# Wakool Shire Council

## Barham Flood Study

## Final Report

October 2014

Cover photograph:  Downstream side of the Barham bridge at the streamflow gauging station site.

# Executive Summary


The Barham Flood Study was commissioned by the Wakool Shire Council. The study has assessed Murray River flooding conditions at Barham.

The study has been carried out in accordance with the NSW Government's Floodplain Development Manual (2005). The primary objective of the NSW Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods.

In urban areas, the management of flood-prone land remains the responsibility of local government. The NSW State Government provides funding to assist local councils with the development of floodplain risk management plans and their implementation.

The study has been overseen by Council's Floodplain Risk Management Committee. The Committee met regularly during the study to review progress and provide direction for future activities. The investigations carried out as part of this Flood Study may form the foundations for a future Floodplain Risk Management Study.

**Data Review and Community Consultation**

Community consultation and data review activities are documented in Sections 3 and 4 respectively of this report. Community consultation was limited to contact early in the project with those government agencies with an interest in floodplain management at Barham in order to identify any data held by the respective agencies for potential use during the study. A public notice was placed in local newspapers shortly after the study commenced to make the general public aware of the project.

The data review activities focused on the available streamflow gauging records for the Murray River at Barham, past reports, past recorded flood levels and the available ground survey and river channel survey data.

A draft version of this report was placed on public exhibition for a four week period in July / August 2014. No submissions were received at the end of the public exhibition period.

**Hydrology**

The hydrology analysis activities are documented in Section 5 of this report. Hydrology analysis was limited to flood frequency analysis of the gauging station records for the Murray River at the Barham gauge.

The adopted 100 year average recurrence interval (ARI) peak design flow derived from the flood frequency analysis is 35,900 ML/day. The design flow range is very compressed due to upstream Murray River flooding influences. In large flood events, above a threshold of about 30,000 ML/day, the majority of the Murray system flow discharges via the Edward / Wakool river system, bypassing the Murray River towns of Barham, Murray Downs and Tooleybuc.

The flood frequency analysis results for the Barham data suggest that the highest recorded event in 1917 was equivalent to a 100 year ARI event. The equal second highest recorded events in 1916 and 1956 are equivalent to a 50 year ARI event. The highest recorded event since 2000 occurred in December 2010 and was equivalent to a 5 year ARI event.

**Hydraulic Modelling - Calibration**

The hydraulic modelling calibration activities are documented in Section 6 of the report.

Hydraulic modelling was carried out using the TUFLOW model. All of the study area floodplain was represented using two dimensional modelling techniques based on a 10 metres grid. The

terrain data sources used consisted of 2001 LiDAR data of the out of channel floodplain, surveyed cross sections of the river channel obtained in the 1980s by Victorian authorities and surveyed crest heights of the NSW side levee banks obtained in 2013 for this project.

The TUFLOW model was calibrated using recorded flood height data from the 1956 and the 1975 floods. The model was calibrated to achieve the optimum level of agreement between the available recorded flood heights and the modelled flood heights. The level of agreement achieved is considered satisfactory after taking into account the accuracy limitations of recorded flood height marks.

**Hydraulic Modelling – Design Flood Events**

The modelling results for the 5, 10, 20, 50, 100, 200 and extreme event are described in Section 7 of the report.

Flood map outputs associated with the design event modelling are included in Appendix A (design flood extents and heights), Appendix B (provisional flood hazard maps), Appendix C (hydraulic category maps) and Appendix D (flood profile plan).

**Flood Impacts**

Notable features of flooding conditions as derived from the modelling results are summarized as follows:

- Peak 100 year ARI modelled flood level at the Moulamein Road bridge is below the bridge soffit level.
- Based on the modelled flood levels and the 2013 surveyed levee crest heights, the levee system upstream of Barham is overtopped at multiple locations. Floodwaters overtopping the levee discharge northwards leading to inundation as shown on the maps included in Appendix A.
- The levee system at Barham (i.e. between the Barham Lakes Caravan Park and Hudson Creek) is not subject to overtopping up to and including the 100 year ARI event.
- Downstream of Barham, the levee system is overtopped at localised locations north of Hudson Creek resulting in some backwater flooding notably in the area between the river channel and the North Barham Road.

The hydraulic modelling results assume that no topping up of levee banks takes place. In previous major floods at Barham (e.g. 1956, 1975 and 1993), levees were able to be topped up or strengthened given the response time available due to the slow rate of rise of floodwaters. Consequently the mapped extent of inundation at Barham differs from that which was experienced in past major floods.

Overall flooding impacts on existing development at Barham in future floods are expected to remain low. The most potential for flood damage lies with a rapid major breach of the levee system. The risk of this happening is relatively low as the levee heights and associated hydraulic pressure on the levee system are low.

Most of the areas zoned to allow future development at Barham are shown to be flood affected in a 100 year ARI event. These areas are generally classified as Low Hazard and Flood Fringe which indicates that the flood risks are low.

The study has focused on reliably defining flooding conditions on the NSW side of the river. Far less emphasis has been placed on defining flooding conditions on the Victorian side of the river which includes the Gunbower Island area. The flood mapping on the Victorian side of the river is therefore indicative only and not necessarily reliable or representative of actual conditions.

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# 1. Introduction

The NSW Government's Flood Prone Land Policy is aimed at providing solutions to existing flooding problems as well as ensuring that new development within flood prone areas is compatible with the prevailing flood risk and does not create additional problems.

The Barham Flood Study has been undertaken to provide the Wakool Shire Council and other stakeholders with an up to date understanding of Murray River flood risks at Barham (refer to Figure 1). This will assist Council and other government agencies to make appropriate decisions in relation to future land use planning and also provide the basis from which to proceed with the development of a floodplain risk management study and plan to mitigate flood risks.

Past floods are understood to have caused limited damage at Barham. Previous reports indicate that the levees present combined with sandbagging efforts in the floods of 1956, 1975 and 1993 protected the town from river system flooding.

This Flood Study represents the first step in the floodplain management process as set out by the NSW Floodplain Development Manual (2005). The four steps are:

- Flood Study – technical assessment to define the nature and extent of flooding under existing conditions;
- Floodplain Risk Management Study - evaluates management options for the floodplain giving consideration to hydraulic, environmental, social and economic issues;
- Floodplain Risk Management Plan – formal plan prepared which outlines the adopted strategies to manage flood risk and flood management issues; and
- Plan Implementation – measures nominated by the plan are put in place.

The Barham Flood Study was carried out concurrently with studies at Murray Downs and Tooleybuc. Separate flood study reports have been prepared for each of these three towns.

The study was undertaken in the following stages:

- **Stage 1 – Data Collection**. This stage encompassed consultation activities relevant to the flood study phase, the review of existing available data, the identification of additional data required to be obtained for the later stages and the confirmation of the approach for the subsequent stages.
- **Stage 2 – Hydrology**. This stage involved flood frequency analysis of historical recorded flows in order to identify appropriate design flows within the study area.
- **Stage 3 – Preliminary Hydraulic Modelling**. This stage encompassed establishment and calibration of the study area hydraulic models and a draft 100 year average recurrence interval (ARI) flood profile.
- **Stage 4 - Final Hydraulic Modelling and Related Tasks**. This stage consisted of hydraulic modelling of the range of required design flood events, the preparation of flood mapping, assessment of climate change potential impacts and location specific flood output data at points of interest.
- **Stage 5 – Draft Flood Study Report**. Draft final report prepared detailing all of the investigations.

- **Stage 6 – Final Flood Study report.** The draft report will be updated as appropriate to take into account any comments received from the Committee.
- **Stage 7 – Project Completion and Handover of Study Materials**. This final stage will involve the handover of project outputs including both electronic and hard copy deliverables.

The Flood Study was overseen by Council's Floodplain Risk Management Committee. The Committee met on five occasions during the project. Progress reports were submitted to the Committee at the completion of Stage 1 and Stage 3. This Flood Study report was submitted to the Committee in draft form in May 2014 before being updated and then placed on public exhibition during July / August 2014.

Two terms are typically used to define the severity of flood events in Australia. The term Average Recurrence Interval (ARI) refers to the long term average number of years between the occurrence of a flood as big as or larger than the selected event. A flood with a discharge as great or greater than the 20-year ARI flood event for example will occur on average once every 20 years. The term ARI is used in this report to describe the size of flood events as it is generally well understood by most.

The alternative term is Annual Exceedance Probability (AEP). This term expresses the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. A 5% AEP event has a 5% chance (i.e. one in twenty) of being equaled or exceeded in any one year.

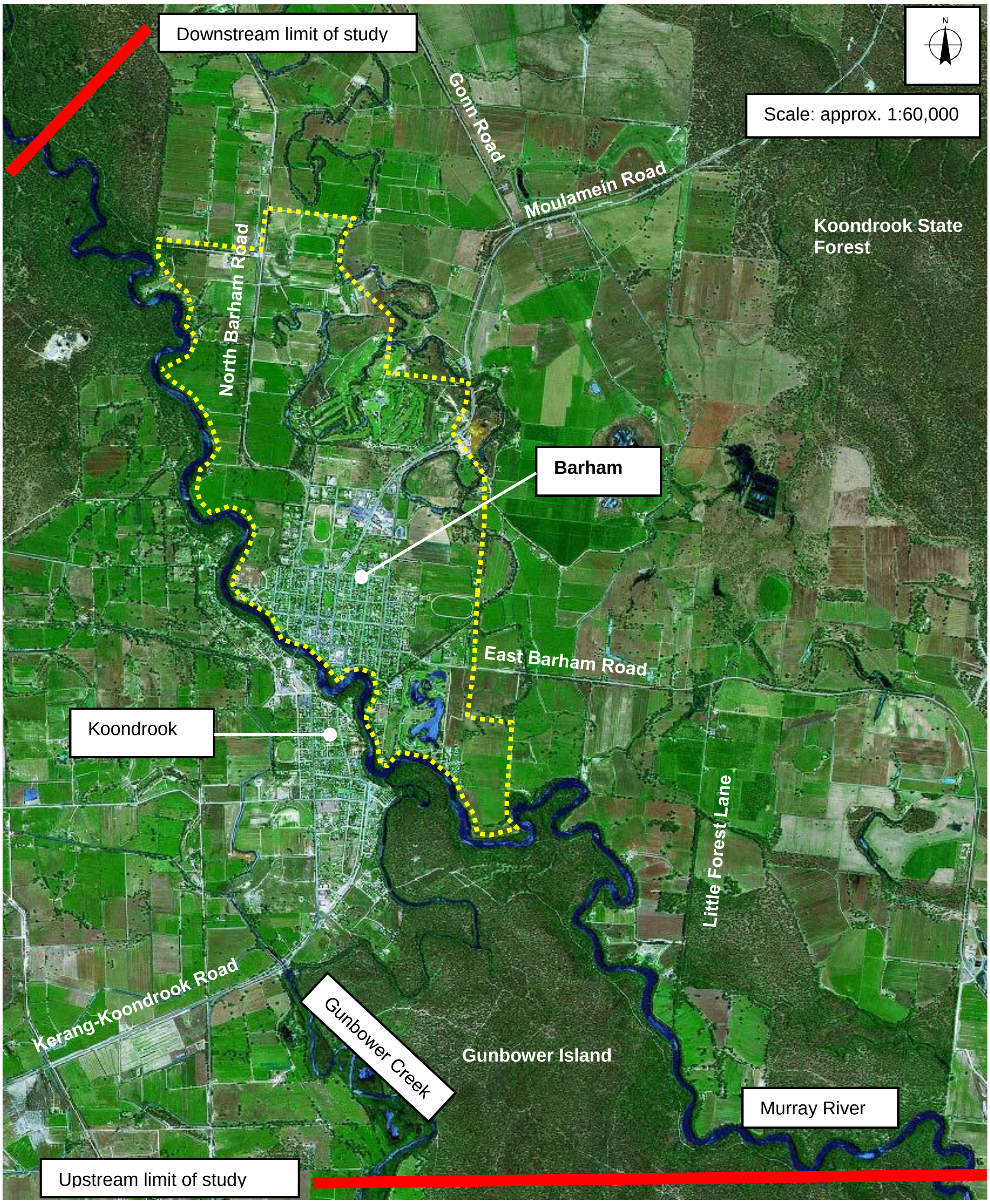



Figure 1 Study Area Plan

# 2. Study Area Description

## 2.1 Barham Township

Barham is located on the NSW side of the Murray River, opposite the Victorian township of Koondrook (refer to Figures 1 and 2). Barham has the largest township population within the Shire of 1,100 based on the 2006 Census.

Barham supports the broadest range of retail and commercial activity in the Shire including retail services and various professional and medical services. There are a range of tourism activities including clubs, motels and caravan parks. A small number of industrial land use properties are located north of the township.

A significant attraction at Barham is the sport and recreation facilities, including Barham Lakes and the Barham Golf and Country Club.

Based on dwelling application figures documented in the Wakool Shire LEP Review 2009 Land Use Strategy Report, Barham is the fastest growing town in the Shire. Average annual dwelling applications between 1997 and 2007 averaged 9.3. In order to capitalise on the potential growth opportunities available at Barham, the 2009 Land Use Strategy Report nominates principles which include:

- Ensuring an appropriate supply of residential land in attractive and serviceable locations.
- Ensuring land intended for residential purposes is not subject to flooding or other environmental purposes.

## 2.2 Catchment Description

The Murray River catchment upstream of Barham is large, encompassing the catchments of the Upper Murray River, Mitta Mitta River, Kiewa River, Ovens River, Goulburn River and Campaspe River. The total catchment area is 43,000 km$^2$.

There are major storages located at Dartmouth Dam on the Mitta Mitta River, the Hume Dam on the Murray River upstream of Albury, and the Eildon Dam on the Goulburn River.

Not all flows from the upstream catchment discharge past Barham. Much of the upstream flow discharges into the Edward and Wakool River system. This large complex anabranch system bypasses to the north of Barham, returning to the Murray River 20 km downstream of Tooleybuc.

The following factors influence flooding conditions at Barham (refer to Figure 3):

- The Barmah choke is a natural floodplain constriction located in the vicinity of Barmah, upstream of Echuca. This natural constriction results in the majority of Murray River flood flows upstream of Barmah being directed northwards into the Edward River system.
- Flows downstream of Echuca inundate the adjoining Gunbower Forest, Perricoota Forest and Koondrook Forest. Outflows from the NSW side forests occur into the Wakool River system to the north via the Thule Creek and Barbers Creek floodways. This release of flow into the Wakool River system significantly reduces the flow carried by the Murray River at Barham / Koondrook.
- Levees or natural high ground on both the NSW and Victorian side banks funnel the Murray River flow past Barham and Koondrook.

Flooding at Barham is therefore largely dependent on the rate and timing of flows being discharged by the Campaspe River and Goulburn River tributaries.

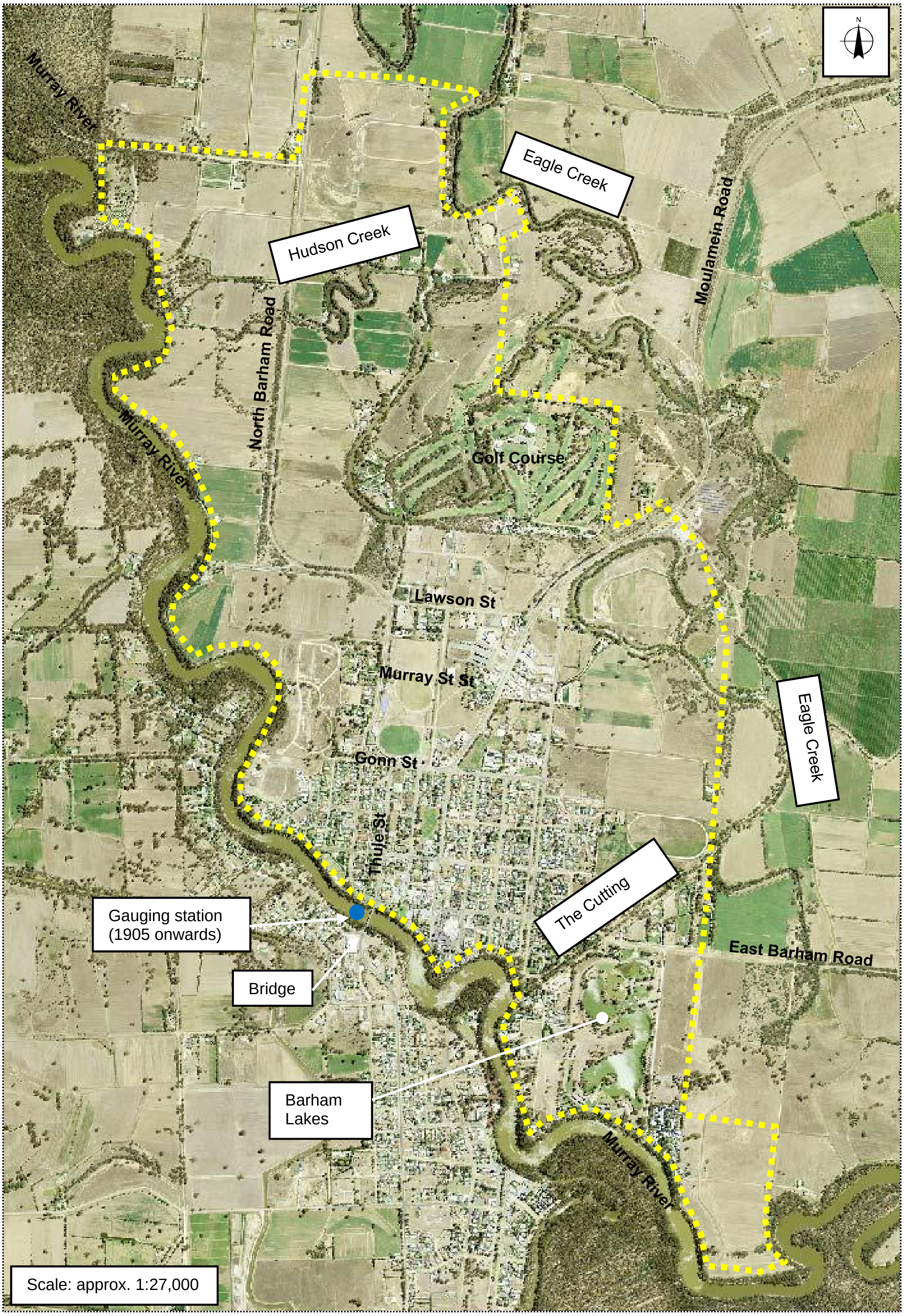



Figure 2 Barham Local Features

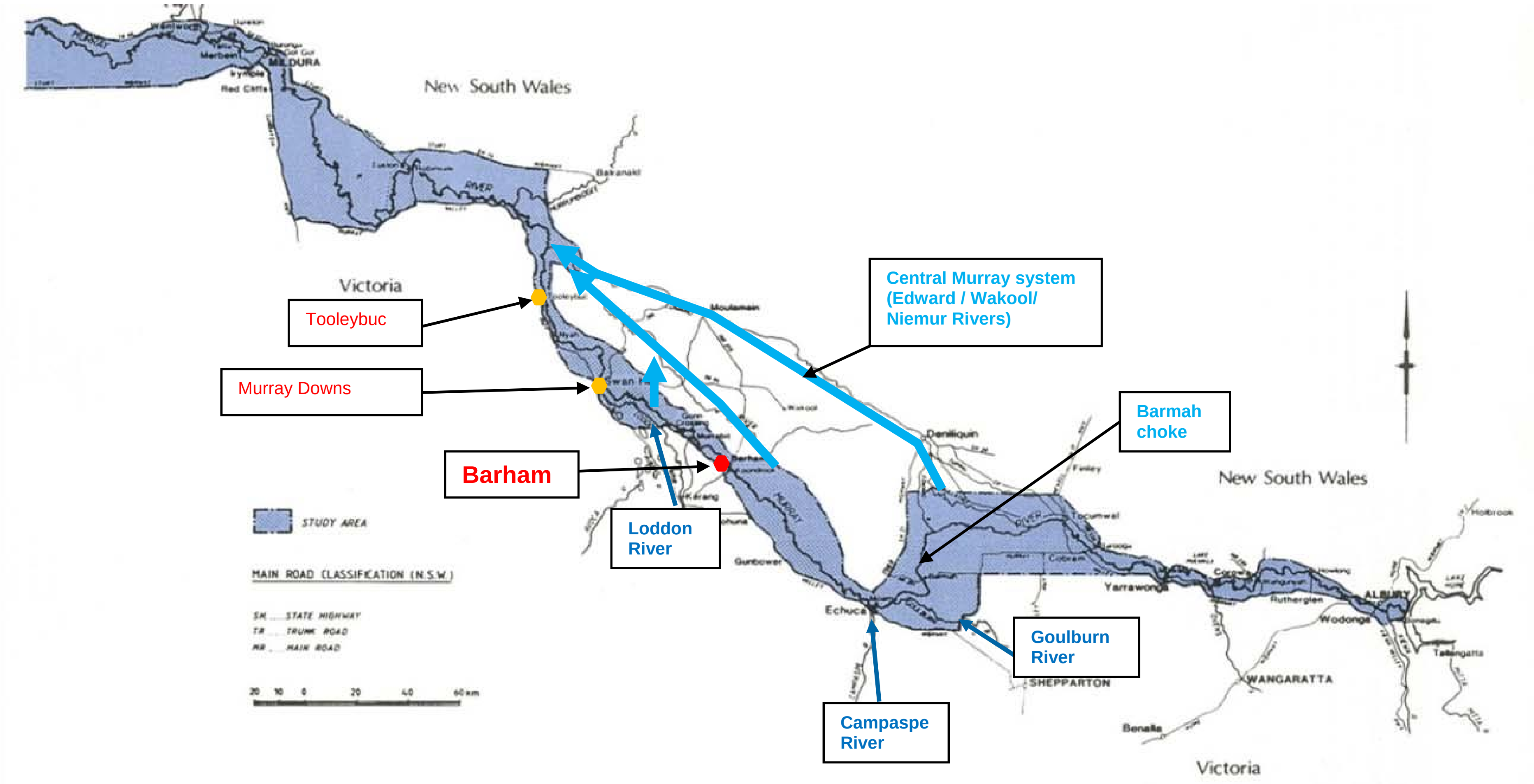



Figure 3 Murray River Floodplain System Features

(modified extract from 1986 Murray River Floodplain Management Study)

A record high flood in the Campaspe River in January 2011 did not lead to major flood concerns at Barham with the flood peaking at Barham well below the town levee crest. Only minor flooding occurred in the Murray River tributaries upstream of the Campaspe River in January 2011. Major inflow contributions from the Goulburn River in addition to the Campaspe River are required to induce flood levels similar to the highest flood events experienced at Barham.

## 2.3 Floodplain Description

The levee system protecting Barham is understood to have been constructed in the early 1900s following the establishment of the township in the late 1800s.

The existing levee system consists of a series of levee segments which provide protection from both the adjoining Murray River and the Barbers Creek system to the east (refer to Figure 5).

The levee on the NSW side of the Murray River varies markedly in size. In some places there is no levee given the natural high ground present. The Murray River is perched at Barham, with ground levels falling away from the river (refer to Figure 4). This is important as once flood levels overtop the NSW side levee, widespread flooding could potentially occur.

The Gunbower Island area is located south of Barham. Gunbower Creek to the west and the Murray River to the east enclose this area.

The Koondrook Forest is located to the east of Barham. The recently completed Koondrook-Pericoota Flood Enhancement Works project has involved the construction of a large perimeter levee bank around the perimeter of the Forest upstream of the Moulamein Road. This levee will essentially act as a flood protection levee for Barham, notwithstanding that the reason the levee was constructed was to allow environmental watering of the forest, not as a flood mitigation measure. The uniform design crest height of the levee is 78.8 m AHD. The design pool level for watering events is 78.5 m AHD.

Eagle Creek is a local waterway on the east and north sides of Barham. The creek discharges northwards through the Barham golf course and into the broader floodplain to the north of Barham. A man made excavated cutting channel provides a connection between the Murray River and Eagle Creek at Barham. A regulator structure at Jamieson Street controls flows within the cutting.

There is one river bridge crossing between Barham and Koondrook. The bridge was completed in 1904 and includes a lift span to allow vessels to navigate through the opening.

In addition to the levee bank which parallels the Murray River channel, there are also a number of raised roads and irrigation infrastructure which have at various times acted as defacto levee banks. They are listed as follows (refer to Figures 1 and 5):

- East Barham Road
- Little Forest Lane
- Bringan Channel (irrigation channel with spoil banks either side).
- Lilfords Lane
- Moulamein Road
- North Barham Road
- Gonn Road

Barham does not rely on any of the above for protection from flooding.  The primary levee protection is provided by the levee which parallels the Murray River channel and the recently reconstructed perimeter levee bank around the Koondrook Forest (Barbers Creek floodway).

The various local roads and channel banks provide a potential secondary line of protection if the main levee banks are breached.

Eagle Creek is the most prominent local waterway at Barham.  Most of the town stormwater system drains into Eagle Creek.  The headwaters of the creek are located on the south side of the East Barham Road.  The creek route meanders northwards down the east side of Barham and continues north westwards parallel with the Gonn Road.  Eagle Creek is essentially a remnant floodplain channel formed by Murray River floodplain flows.  The catchment area draining directly into Eagle Creek is very small.  The Eagle Creek Cutting (refer Figure 2) allows flows from the Murray River to be directed into Eagle Creek for irrigation purposes.  The Cutting has a regulator structure at Jamieson Street.

Hudson Creek is also a remnant floodplain channel connected to Eagle Creek on the north side of Barham.  Backwater flooding can occur from Eagle Creek up the Hudson Creek.  There is no longer any cross drainage structure at the Hudson Creek North Barham Road crossing.

## 2.4 Historical Flood Events

The most significant flood events at Barham based on the records at Station 409005 from 1905 onwards are 1917, 1916, 1956, 1975 and 1993 in order of magnitude as listed in Table 1.

Flooding impacts are not well documented for the 1916 and 1917 events.  Previous reports indicate that the levees present combined with sandbagging efforts in the floods of 1956, 1975 and 1993 protected the town from river system flooding.

Previous report accounts in regards to past floods  at Barham are repeated as follows:

- Gutteridge Haskins & Davey, 1986.  Refers to extensive sandbagging along the Eagle Creek cutting in the 1956 flood which prevented floodwater from entering the village. Also refers to major sandbagging along the private levee route adjoining the Koondrook Forest in the 1974 flood.
- Gutteridge Haskins & Davey, 1995.  Refers to floodwater around Pollock Swamp threatening Barham in 1974 and 1975, with protection provided by the Bringan Channel.

### Table 1 Five Highest Recorded Flood Heights at Barham since 1905

| Event Rank | Year | Peak Flood Height metres (m AHD) | Peak Flow (ML/day) |
|---|---|---|---|
| 1 | 1917 | 6.22 (77.50) | 36,000 |
| 2 | 1916 | 6.15 (77.43) | 34,900 |
| 3 | 1956 | 6.12 (77.40) | 34,400 |
| 4 | 1975 | 6.12 (77.40) | 34,400 |
| 5 | 1993 | 6.10 (77.38) | 34,000 |

Notes:

1. Levels and flows are at the Barham streamflow gauge 409005 located on the downstream side of the Barham-Koondrook bridge.
2. Gauge zero datum is 71.28 m AHD. Note that prior to 1998, the gauge zero datum was specified to be 71.435 m AHD. During 1998 or thereabouts, this was corrected to the current value of 71.28 m AHD following an AHD shift at Barham. The absolute elevation of the gauge zero is understood to have not changed since 1905.

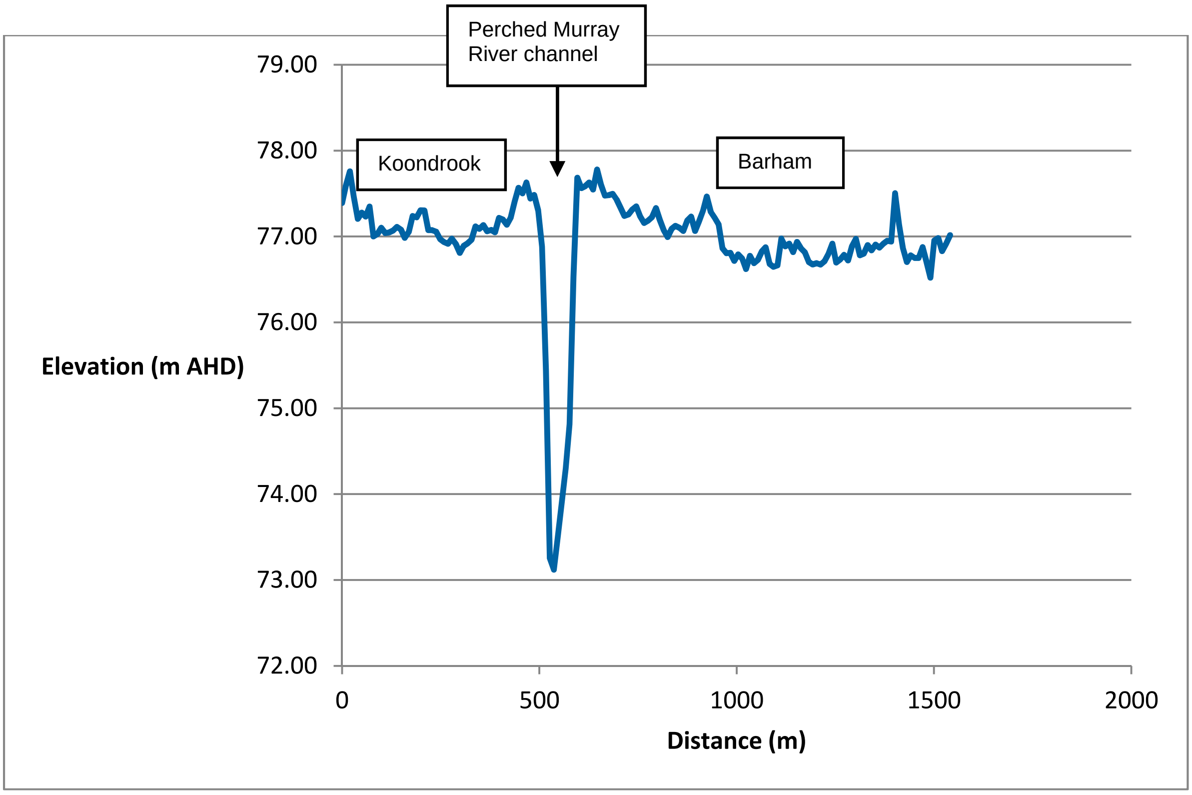
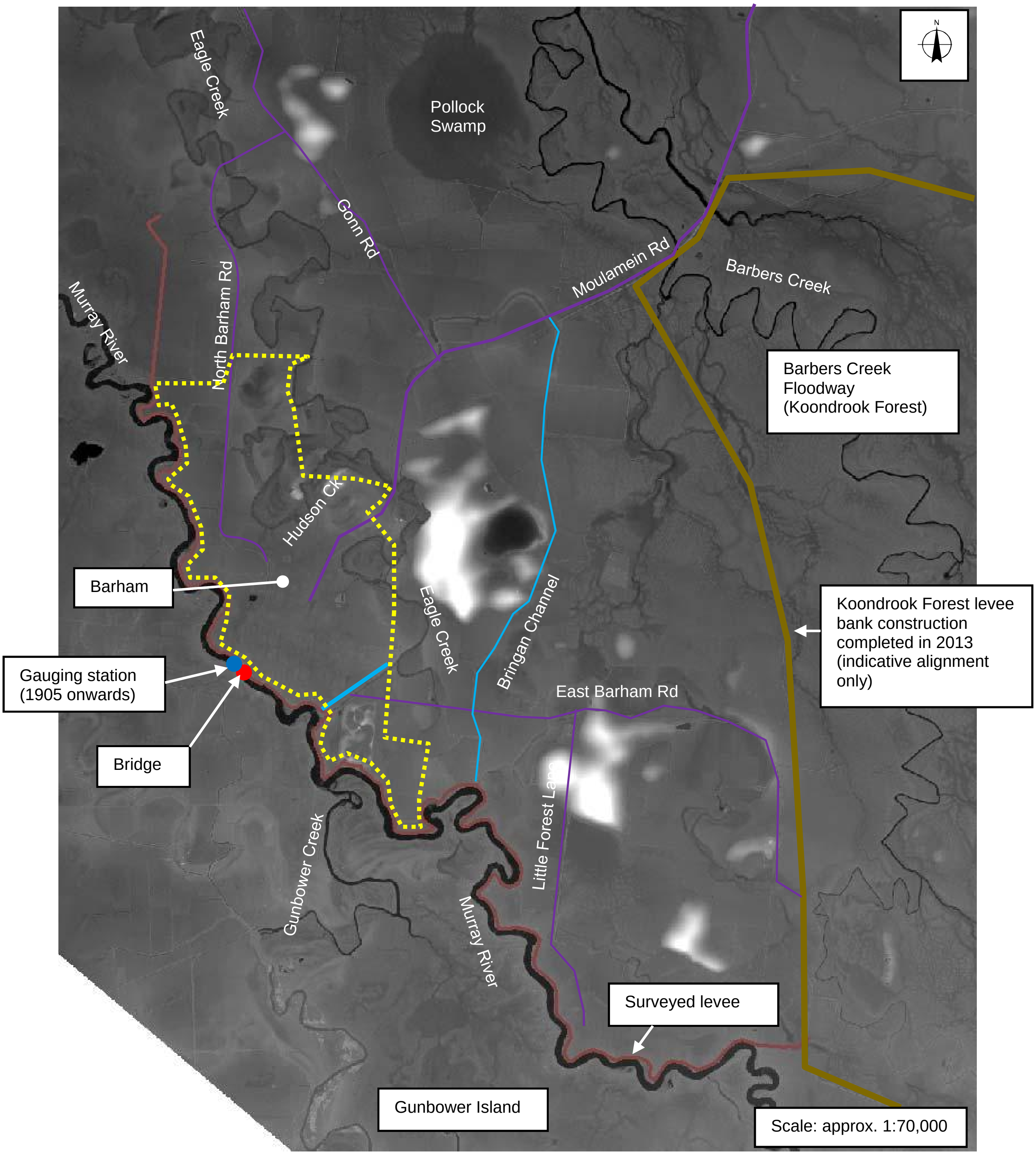



Figure 4 Typical Floodplain Cross Section at Barham




## Figure 5 Floodplain Features

(base imagery is 2001 LiDAR image)

**Photograph 1 Typical 'natural' high ground levee at Barham (next to Bowling Club)**


**Photograph 2 View from Teddys Place towards constructed levee and river**

**Photograph 3 Typical rural levee upstream of Barham**

**Photograph 4 Koondrook Forest levee bank**

# 3. Community Consultation

## 3.1 Overview

The primary objectives in relation to consultation activities during the flood study phase are as follows:

- Informing the relevant government agencies that the study is being undertaken, outlining its objectives and inviting agencies to provide any relevant data they may hold and / or advise of any particular issues of concern.
- Similarly informing relevant local community groups.
- Similarly informing the general public.

## 3.2 Floodplain Risk Management Committee

Wakool Shire Council formed a Floodplain Risk Management Committee in 2012.

The Committee consists of representatives from the following organisations:

- Wakool Shire Council, both staff and Councillor representatives.
- Office of Environment and Heritage.
- NSW Murray Region State Emergency Service.
- Local community representatives.
- The above Committee met on five occasions during the flood study. Meetings were held in March, May, July and December 2013, and in June 2014.

## 3.3 Stage 1 Consultation Activities

A public notice was placed in the local newspapers in May 2013 in regards to the flood study. The notice provided basic details in regards to the initiation of the flood study, its objectives and contact details for any community members wishing to either find out further information regarding the project or pass on their thoughts.

Other government agencies with an interest in Murray River floodplain management at Barham were contacted shortly after the commencement of the study. This included the following organisations:

- Murray Darling Basin Authority.
- North Central Catchment Management Authority.
- Goulburn-Murray Water.

## 3.4 Public Exhibition of Draft Flood Study Report

The draft Barham Flood Study report was submitted to the Floodplain Risk Management Committee in May 2014. The draft report was then updated following a meeting of the Committee in June 2014 to reflect feedback received from the Committee. The draft report was then placed on public exhibition for a four week period in July / August 2014.

No submissions were received at the end of the public exhibition period. The report was subsequently finalised.

# 4. Data Collection and Review

## 4.1 Hydrologic Data

Gauged streamflow records are available for the Barham station (409005) which has operated since 1905. Streamflows records are also available upstream at Torrumbarry and downstream at Swan Hill.

Given the above, sufficient streamflow records are available for utilising flood frequency analysis to identify design flows.

## 4.2 Flood Height Data

Recorded flood heights are particularly useful for calibration of hydraulic models, particularly if corresponding gauged streamflow data is available, which is the case at Barham.

In the case of the Barham study area, flood height marks have been recorded on various plans. The primary source for flood height marks was the Victoria Flood Data (VFD) database. This database was initially compiled in 2000. It includes a GIS layer for recorded / observed spot elevation flood height marks from past flood events, based on a search of all available data at the time of the original database establishment. Within the study area reach of the Murray River floodplain, there are:

- Eight 1975 event recorded flood height marks
- Six 1956 event recorded flood height marks
- Two 1981 event recorded flood height marks
- Two 1983 event recorded flood height marks

Victorian authorities have previously defined 100 year ARI flood levels for this section of the Murray River. The levels are 0.25 metres higher than the recorded 1975 flood height marks and are generally viewed as conservatively high.

## 4.3 Previous Reports

The Barham Town Levee Investigation (Gutteridge Haskins & Davey, 1995) assessed various levee options for achieving 100 year ARI flooding protection at Barham. No hydraulic modelling or flood damage analysis was undertaken as part of the 1995 study. This is the only previous study focused specifically on flooding issues at Barham.

Other reports with links to flooding at Barham are:

- Murray River Flood Plain Management Study (Gutteridge Haskins & Davey, 1986). This report provides an overview of flooding characteristics and management issues for the Lake Hume to South Australia border reach of the river.
- Flood Data Transfer Project – Murray River Basin Report and the Shire of Gannawarra Flood Mapping Report (Egis Consulting, 2000). These reports were prepared as part of the Victorian statewide Flood Data Transfer Project commissioned by the Department of Natural Resources and Environment.
- Koondrook Levee Investigation (North Central CMA, early 2000s). The CMA has advised that a crest level survey of the Koondrook's levee was undertaken in the early 2000s. The levee was subsequently raised where required to the 100 year ARI flood level.
- Edward, Wakool and Niemur Rivers – Stages 1, 2 and 3 Areas – Floodplain Risk Management Study (Earth Tech, 2008). This report was prepared for DECCW and

documents a rural floodway network within the Wakool Shire Council, which includes the Barbers Creek floodway to the east and north of Barham.

- Floodplain Management Plan – Wakool River Stage 2 – Moama-Moulamein Railway to Gee Gee Bridge (DECCW, 2011). The gazetted floodplain management plan for the rural area east and north of Barham.
- RiverLife Estate Barham – Flood Risk Assessment (GHD, March 2011). Assessment of flood risk issues at a development site on the south side of Barham.
- Lots 14, 15 and 16 – DP1039025, Yarrein Street, Barham – Flood Risk Management Plan (GHD, July 2011). This report is a site specific plan which focuses on flood risks to a development site at Yarrein Street in north Barham.
- Koondrook-Pericoota Flood Enhancement Works. Various commonwealth and state government agencies involved in the planning, design and construction of works between 2004 and 2012 to provide environmental watering of the Koondrook Pericoota Forests. The works include channels, regulators and levees. One of the upgraded levees is the levee bordering the Koondrook Forest / Barbers Creek floodway to the east of Barham.

## 4.4 Terrain Elevation Data

The following terrain data sources informed the study:

- 2001 LiDAR data. This data was checked against some site survey data provided by the Wakool Shire Council. The resultant comparison identified that the LiDAR elevations were consistently between 0.1 and 0.3 metres below the site survey elevation data. The data was subsequently lowered by a uniform 0.2 metres prior to its use in the current study.
- Six Murray River channel cross sections from a 1980 State Rivers and Water Supply Commission survey.

The NSW RMS supplied some general arrangement plans of the 1904 Murray River bridge.

A levee crest height survey was undertaken for the NSW side levees within the study area. The survey data was obtained in September 2013. The surveyed crest heights were used to define the NSW side levees within the hydraulic model.

One important survey issue at Barham is the AHD datum shift which occurred in 1998. The gauge zero datum at the Barham Murray River gauging station (409005) was lowered from 71.435 m AHD to 71.28 m AHD in March 2005 (i.e. lowered by 0.155 m). The physical location and elevation of the gauge has not changed since the gauge was set up in 1905. A recorded flood height of 6.0 m at the gauge in 2014 is the same height as a recorded flood height of 6.0 m in 1975. The highest peak flood height recorded at the Barham gauge was 6.22 metres in 1917. The AHD elevation of the peak 1917 flood height is 77.50 m AHD, which differs from the 77.66 m AHD quoted in reports prepared prior to 1998.

## 4.5 Existing Levees

The existing levee at Barham is generally a low level levee due to the existing ground levels typically being only marginally below the previously defined 100 year ARI flood levels. In some places, there is no levee present at all due to the naturally high ground levels.

The Jamieson Avenue regulator structure prevents backwater flooding via The Eagle Creek Cutting.

Current development activity is most notable on the north side of town (i.e. Teddys Place estate area). A continuous levee parallels the river course in this area.

Although somewhat suspect in terms of height and strength, the existing levee system has been sufficient to protect Barham from flooding since the early 1900s, although sandbagging and topping up of levee segments is reported to have taken place in large floods (e.g. 1956, 1975, 1993).

The recent Koondrook-Perricoota project has included the construction of a major confinement bank which surrounds the Barbers Creek floodway to the east of Barham on the upstream side of the Moulamein Road.

On the Victorian side of the river at Koondrook, the naturally high ground closest to the river channel either results in a low level levee bank or in some sections no levee at all.  On the upstream side of the town, a levee is present which parallels Gunbower Creek.

# 5. Hydrology

## 5.1 Approach

The estimation of design flood flows for the study area was undertaken using flood frequency analysis techniques. This approach was suited given the availability of 100 years of continuous flow records at Barham.

Flood frequency analysis is the statistical analysis of recorded flows. The resultant statistically derived design flows are therefore a reflection of past floods for the period of available record.

The alternative approach to flood frequency analysis is deterministic rainfall / runoff (hydrologic) modelling. Rainfall / runoff modelling is generally the favoured approach for smaller catchments where concurrent rainfall and streamflow data allows for calibration of models. For larger catchments with complex flow exchanges influenced by hydraulic conditions, deterministic modelling becomes increasingly difficult, if not impossible. Given the size and complexity of the upstream catchment and the availability of the recorded streamflows at Barham, hydrologic modelling was not undertaken.

## 5.2 Streamflow Data

Streamflow records utilised for Barham consisted of the following station data:

- Murray River at Barham (409005). This station was established in 1905 and is located on the downstream side of the Barham-Koondrook bridge. The bridge was constructed the previous year in 1904.
- Murray River at Torrumbarry (409207). This station was first established in 1895. The station is located on the downstream side of Torrumbarry, approximately 45 km upstream of Barham.

The station at Barham has operated semi continuously since 1905. The highest gauged event was in 1975 to a height of 6.07 m (77.35 m AHD). The rating table is therefore expected to be reliable over the full range of flood events up to at least this height.

The gauge at Barham measures only the floodplain flow past the gauge. The majority of the flow discharging past Torrumbarry bypasses Barham to the north, being discharged via the Barbers Creek floodway (Koondrook Forest) into the Wakool River system.

The peak flow data at the Torrumbarry gauge is influenced by the construction of the Torrumbarry Weir during the period 1919 to 1923. The peak recorded flows for the 1916 (95,200 ML/day) and 1917 (94,800 ML/day) events are substantially higher than anything recorded since 1923, of which the 1956 peak flow of 66,000 ML/day is the highest.

Flooding at Barham is largely dependent on inflows into the Murray River from the Goulburn River and the Campaspe River, as these two tributary inflows are downstream of the Barmah choke. The Barmah choke has an upper limiting capacity of approximately 35,000 ML/day. Flows in the Murray River above the choke capacity are discharged into the Edward River system. Changes which have occurred since 1900 in the Murray River catchment above the Barmah choke (e.g. Hume Dam, Dartmouth Dam) will not have had a significant impact on flooding conditions at Barham.

Lake Eildon was completed in 1956. It stores water from the upper Goulburn River catchment. Lake Eildon has the potential to mitigate flood peaks in the downstream Goulburn River and to a lesser extent within the Murray River downstream of the Goulburn River junction.

Lake Eppalock was completed in 1964. It stores water from the upper Campaspe River catchment. Similar to Lake Eildon, Lake Eppalock has some potential to reduce downstream peak flows in the Campaspe River and to a lesser extent the Murray River downstream of Echuca.

Levee construction along the Murray River commenced in the second half of the 1800s. Extensive levee systems were in place including at Barham by the early 1900s. Most of these levees remain in place.

More recently, works associated with the Koondrook Pericoota Flood Enhancement project have been constructed upstream of Barham. These works have included a raised levee bordering the Koondrook Forest and flow regulators on the upstream side of the Barham-Moulamein Road. The levee bank bordering the Koondrook Forest has been raised to 78.8 m AHD, above the 100 year ARI flood level. The regulators have been sized to pass in excess of the 100 year ARI design flow.

Sections of the levee at Barham have been raised at different times. The township has not been subject to river flooding in any floods since at least 1917, although sandbagging efforts are reported to have been required during the 1956, 1975 and 1993 floods.

## 5.3 Flood Frequency Analysis Results

The flood frequency analysis was undertaken using the computer program FLIKE. FLIKE is a program which uses the Bayesian approach and up to five probability models which are commonly used in flood frequency analysis.

The flood frequency analysis results are given in Table 2. The results coincide with fitting the data to an LPIII distribution. The full period of record was used for the analysis (refer to Table E1 in Appendix E), given the absence of any specific known changes which would have significantly altered flow characteristics at the gauging station site.

Table 2 Barham – Design Flow Estimates

| ARI (years) | Peak Design Flow (ML/day) | | | |
|---|---|---|---|---|
| | 1986 Study ( ) – indicates stage height | 1995 Study ( ) – indicates stage height | **2014 Study ( ) – indicates stage height** | 2014 Study 5% & 95% confidence limits |
| 5 | - | - | **28,400 (6.00)** | 27,200 – 29,600 |
| 10 | - | - | **31,100 (6.08)** | 29,900 – 32,400 |
| 20 | 34,400 (6.13) | 34,000 (6.12) | **33,100 (6.13)** | 32,000 – 34,500 |
| 50 | 34,800 (6.15) | 35,000 (6.17) | **34,900 (6.17)** | 33,600 – 36,700 |
| 100 | 34,900 (6.16) | 36,000 (6.22) | **35,900 (6.20)** | 34,600 – 38,200 |
| 200 | - | 37,500 (6.25) | **36,700 (6.22)** | 35,300 – 39,200 |

Notes:

1. 1992 Study – Gutteride Haskins & Davey et al – Murray River Floodplain Management Study.
2. 1995 – Gutteridge Haskin & Davey – Barham Town levee Investigation.
3. Levels and flows are at the Barham streamflow gauge 409005 located on the downstream side of the Barham-Koondrook bridge.
4. Gauge zero datum is 71.28 m AHD.

The resultant design flows are very similar to the previous study estimates, particularly the most recent 1995 study.

The design flows are compressed within a very narrow range. This is due to upstream Murray River flooding influences (e.g. Barmah Choke, Barbers Creek floodway) which results in the majority of river flows above a threshold of approximately 30,000 ML/day being discharged by the Edward / Wakool system, thereby bypassing Swan Hill.

Based on the adopted design flows given in Table 2, the equivalent ARI of the five highest peak flood level events recorded are listed as follows:

- 1917 (6.22 m ) – 100 year ARI
- 1916 and 1956 (both 6.16 m) – 50 year ARI
- 1939 (6.13 m) – 20 year ARI event
- 1920 and 1975 (6.12 m) – 18 Year ARI event

Since 1993, the highest peak flood occurred in December 2010, peaking at 5.99 m. This was equivalent to around a 5 year ARI event, based on the current study flood frequency analysis results.

## 5.4 Design Event Inflow Approach

A review of the gauged flow data for past floods at Barham confirms that flow rates rise and fall relatively slowly. Examples are described as follows:

- October 1993. This event peaked at 34,000 ML/day. The flow remained above 30,000 ML/day at Barham from mid September to mid November.
- October 1975. This event peaked in late October at 34,400 ML/day. The flow remained above 30,000 ML/day from mid September through to early December.
- July 1956. This event peaked in late July at 34,400 ML/day. The flow remained above 30,000 ML/day from early June to early October.
- August 1917. This event peaked in mid August at 36,000 ML/day. The flow remained above 30,000 ML/day from late June to early December.

Given the slow rates of rise and fall, the use of steady state flow inputs for the hydraulic modelling will be adopted.

## 5.5 Extreme Event

Extreme event flooding along the Murray River floodplain corridor is extremely complex given the enormous catchment size and the relatively flat terrain conditions along both the NSW and Victorian sides of the river. The levees paralleling much of the river route will be overwhelmed in an extreme event resulting in the inundation of vast areas adjoining the areas subject to inundation in less severe events.

Accurate modelling of extreme events would require a huge amount of effort and expense. This could not be justified given the low probability of occurrence. Additionally the available warning time at Barham would remain favourable (i.e. approaching a week or more) allowing for evacuation if the need ever arises.

In accordance with the Brief, the approach adopted was to assume a multiple of the 100 year ARI event as the extreme design flow. Given the extremely large catchment and terrain conditions, a multiple three times the 100 year ARI flow was adopted. This is arguably a conservatively high figure.

# 6. Hydraulics – Calibration Modelling

## 6.1 Overview

Hydraulic modelling was carried out consistent with the approach outlined in the NSW Floodplain Development Manual. This approach involves the following steps:

- Assembly of the hydraulic model using the available terrain and waterway structure data.
- Calibration of the model using the available historical flood gauged flow data and recorded flood height data.
- Modelling of a range of design floods using the adopted design flow rates derived from the preceding hydrologic assessment and the calibrated hydraulic model.

The availability of digital elevation model (DEM) data for the study area floodplains allowed the use of a two dimensional hydraulic model, TUFLOW, for the hydraulic modelling. TUFLOW is a computational engine that provides two-dimensional (2D) and one-dimensional (1D) solutions of the fee-surface flow equations to simulate flood propagation.

Aspects of the hydraulic model set-ups are described as follows:

- A 10 metres grid spacing was adopted. A finer grid spacing (e.g. 5 metres) would have significantly increased the run time durations.
- The downstream boundary condition was based on an assigned fixed water level consistent with recorded flood heights for historical events.
- The in-channel geometry of the Murray River was defined using surveyed in-channel cross sections obtained by Victorian government agencies during the early 1980s (i.e. by the State River and Water Supply Commission / Rural Water Commission of Victoria). A DEM of the river channel was generated using the available river channel cross section data and read directly into TUFLOW.
- The overbank floodplain geometry and Victorian side levee crest heights were defined using the 2001 MDBA LiDAR terrain elevation data.
- The NSW side levee banks within the study area were subject to a crest height survey to accurately define their crest height along their routes. The survey was undertaken by Northern Land Solutions during August to September, 2013.
- The bridge opening was defined using a combination of plan data and field acquired data.

## 6.2 Limitations

The TUFLOW hydraulic model was developed to simulate flood flow conditions. Although surveyed river channel cross sections have been used to define the channel geometry, the small number of cross sections available means that the river channel is not sufficiently well defined to be able to predict low flow water surface profiles.

Although the study will include the modelling of an extreme flood, this will be performed in a simplified manner. In extreme events, levees on both sides of the river will be overtopped resulting in very large areas being inundated on both the Victorian and NSW sides of the river. It is not practical to assemble models capable of accurately simulating extreme conditions given the vast affected areas and the complex upstream hydraulic conditions.

## 6.3 Hydraulic Model Calibration Approach

Flows for a range of varying size flood events at Barham are compressed within a relatively narrow range due to the upstream floodplain conditions. The Murray River channel and the immediate adjoining floodplain has an upper limiting capacity of approximately 35,000 ML/day at Barham. Flows in excess of this discharge northwards into the Wakool River upstream of Barham via the Barbers Creek floodway.

The following recorded flood heights within the hydraulic model reach at Barham are available:

- Eight 1975 event recorded flood height marks
- Six 1956 event recorded flood height marks
- Two 1981 event and two 1983 event recorded flood height marks

The 1975 and 1956 event recorded flood height marks were used for the model calibration.

A shift in the AHD datum occurred at Barham in around 1998. The datum was moved down by the NSW Government survey authority by 0.15 metres. All AHD heights prior to this were based on the previous datum. Consequently an adjustment downwards of 0.15 metres has been made to the pre 1998 gauging station recorded heights and all the other spot recorded heights within the study area hydraulic modelling reach.

Assumptions made in regards to the hydraulic modelling are listed as follows:

- Steady state flow inputs were used as discussed in Section 2.2.
- Gauged flows: 1975 peak flow – 34,400 ML/day, 1956 peak flow 34,400 ML/day.
- A normal depth derived rating curve and a calculated longitudinal floodplain gradient was initially trialled as the downstream boundary condition. This was however found to produce a downstream boundary water level which was much lower than the recorded flood heights in the vicinity. Consequently a fixed downstream boundary water level coinciding with the recorded flood heights in the vicinity was adopted.
- Possible changes in levee conditions between 1956, 1975 and 2013 were not factored into the modelling. This was primarily due to any changes being extremely difficult to define. Additionally most of the levees appear to have been present in some shape or form for a long period of time. Possible levee breaches may have occurred in the 1956 and 1975 floods leading to lower peak flood heights.
- Flooding conditions on the Victorian side of the reach modelled are approximated by the TUFLOW model. The levee on the west side of the Gunbower Creek, the Koondrook urban levee segments and the Victorian side levee north of Koondrook were assumed to be elevated above the 100 year ARI flood level.
- The NSW side levees were accurately defined using the crest height survey data obtained specifically for this project.

## 6.4 Calibration Modelling Results

The calibration hydraulic modelling results at Barham are presented in Table 3. The location of the recorded flood heights is shown on Figure 6.

Comments on the 1975 calibration modelling results are provided as follows:

- The adopted fixed downstream boundary water level was 76.70 m AHD.
- The modelled heights generated using a main channel Mannings roughness value of 0.055 were consistently higher than the recorded flood heights.

- Reducing the main channel Mannings roughness value to 0.045 generally lowered the modelled flood levels by approximately 0.05 metres, improving the level of agreement achieved with the recorded heights. Reducing the Mannings roughness to 0.035 generally lowered the modelled flood levels by a further 0.05 to 0.06 metres.
- The recorded height for Mark 75-2 is only 0.03 metre lower than the recorded height at the gauge (Mark 75-3), located 2 km upstream. It was not possible to achieve close agreement at both the gauge and Mark 75-2.
- The level of agreement achieved between the modelled and recorded heights at Marks 75-1, 75-3, 75-4 and 75-5 was within +/- 0.14 metres with either of the two lower Mannings roughness values used (0.035 or 0.045).
- Marks 75-6 and 75-7 are both located in the vicinity of Gunbower Creek. The modelled height at these locations is 0.22 metres higher at Mark 75-7 based on a Mannings roughness of 0.045. This could be due to levee factors (i.e. floodwater in 1975 may not have been confined on the Victorian side opposite this location). Mark 75-6 is considered suspect as it is 0.25 metres lower than Mark 75-7, but only 400 metres downstream. The average floodplain hydraulic gradient at Barham is 1 in 7,000.

Comments on the 1956 event calibration modelling results are as follows:

- The adopted fixed downstream boundary water level was retained at 76.70 m AHD (as for the 1975 event calibration (same flow for both events).
- There is a difference of 0.17 metres at Mark 56-1 based on a roughness of 0.045. A match cannot be achieve at this location without compromising the level of agreement reached with the recorded level at the gauging station (Mark 56-2) 2 km further upstream.
- The modelled flood levels at Marks 56-2, 56-3 and 56-4 are within +/- 0.10 metres of the recorded heights based on a roughness of 0.045.
- Consistent with the 1975 modelling results, the modelled heights at Marks 56-6 and 56-8 on Gunbower Creek are significantly higher than the recorded heights.
- Mark 56-7 is one of the few recorded heights well upstream of Barham on the Murray River. The modelled height at this location is in good agreement with the recorded level (i.e. no difference with roughness of 0.035 and 0.05 metres difference with roughness of 0.045).
- The modelled flood level at Mark 56-9 located near the upstream limit of the hydraulic model is in very close agreement with the recorded level (0.01 metre difference based on roughness of 0.045).

Modelling results for lower flow rates than the 1956 and 1975 events support the adoption of a Mannings main channel roughness of 0.045 based on a comparison of the modelled flood level with the gauging station rating curve.

In summary, the modelled TUFLOW flood levels are considered to be in reasonable agreement with the recorded flood levels after taking into account various factors including the assumptions regarding the Victorian side levees, the suspect nature of a few of the recorded heights and other uncertainties (e.g. changes in floodplain conditions between 1956, 1975 and 2013).

The following conclusions are drawn from the modelling:

- The calibration modelling results support the adoption of a main channel Mannings roughness value of 0.045 for the design flood modelling.
- A fixed downstream boundary water level approach is appropriate for the design flood modelling given the calibration modelling outcomes.

### Table 3 Barham – Calibration Modelling Results

| Event (peak flow rate – ML/day) | Mark number | Recorded flood height (m AHD) Unadjusted | Recorded flood height (m AHD) Adjusted | Modelled flood height - m AHD ( ) – modelled minus recorded – m | | |
|---|---|---|---|---|---|---|
| | | | | Channel Mannings roughness 0.035 | Channel Mannings roughness 0.045 | Channel Mannings roughness 0.055 |
| Oct 1975 (34,400 ML/day) | 75-1 | 77.00 | 76.85 | 76.85 (0.00) | 76.85 (0.00) | 76.85 (0.00) |
| | 75-2 | 77.53 | 77.38 | 77.16 (-0.22) | 77.17 (-0.21) | 77.18 (-0.20) |
| | **75-3 (gauge)** | **77.56** | **77.41** | 77.38 (-0.03 | 77.41 (0.00) | 77.44 (+0.03) |
| | 75-4 | 77.78 | 77.63 | 77.69 (+0.06) | 77.75 (+0.12) | 77.79 (+0.16) |
| | 75-5 | 78.00 | 77.85 | 77.92 (+0.07) | 77.99 (+0.14) | 78.04 (+0.19) |
| | 75-6 | 78.05 | 77.90 | 78.29 (+0.39) | 78.35 (+0.45) | 78.38 (+0.48) |
| | 75-7 | 78.30 | 78.15 | 78.31 (+0.16) | 78.37 (+0.22) | 78.40 (+0.25) |
| | | | | | | |
| July 1956 (34,400 ML/day) | 56-1 | 77.49 | 77.34 | 77.16 (-0.18) | 77.17 (-0.17) | 77.18 (-0.16) |
| | **56-2 (gauge)** | **77.56** | **77.41** | 77.38 (-0.03) | 77.41 (0.00) | 77.44 (+0.03) |
| | 56-3 | 77.78 | 77.63 | 77.67 (+0.04) | 77.73 (0.10) | 77.78 (0.15) |
| | 56-4 | 78.20 | 78.05 | 77.90 (-0.15) | 77.96 (-0.09) | 78.00 (-0.05) |
| | 56-5 | 78.13 | 77.98 | 78.29 (+0.31) | 78.35 (+0.37) | 78.38 (0.40) |
| | 56-6 | 78.23 | 78.08 | 78.29 (+0.21) | 78.35 (+0.27) | 78.38 (+0.30) |
| | 56-7 | 78.50 | 78.35 | 78.35 (0.00) | 78.40 (+0.05) | 78.43 (+0.08) |
| | 56-8 | 78.60 | 78.45 | 78.79 (+0.34) | 78.83 (+0.38) | 78.87 (+0.42) |
| | 56-9 | 79.00 | 78.85 | 78.82 (-0.03) | 78.86 (+0.01) | 78.90 (+0.05) |

Note:

1. Location of the recorded flood heights is shown on Figure 6.

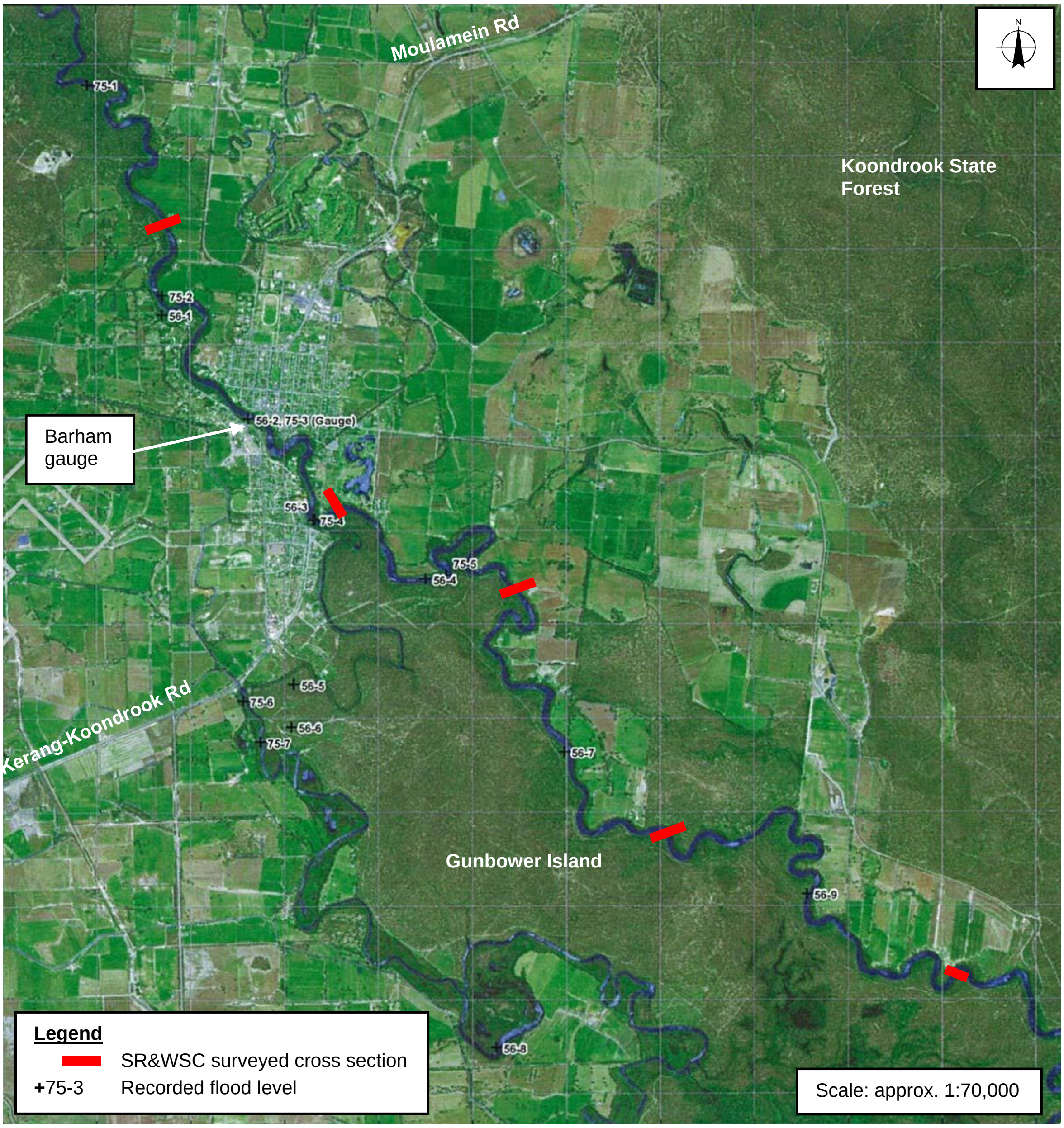



Figure 6 Recorded Flood Heights

## 6.5 100 Year ARI Design Flood Modelling

The calibrated TUFLOW model was used to produce a preliminary 100 year ARI flood profile and extent.

The following details were adopted for the preliminary 100 year ARI modelling:

- Peak design flow. A peak design flow of 35,900 ML/day was adopted based on the flood frequency analysis results. The peak design flow was input as a steady state flow at the upstream end of the hydraulic model.
- Downstream boundary condition. A fixed downstream boundary water level of 76.75 m AHD was adopted. This was adopted based on a review of the Barham gauging station stage discharge rating curve and in particular the difference in height on the rating curve between the calibration flow and the 100 year ARI flow.
- A Manning roughness main channel uniform value of 0.045 was adopted given the calibration modelling results.

The 100 year ARI modelling results indicate the following:

- The modelled flood height at the Barham gauge is 77.44 m AHD. This is well below the bridge soffit level of 79.1 m AHD.
- The existing levee bank crest height or high ground crest height paralleling the river bank opposite the existing town area is above the modelled 100 year ARI flood profile. No overtopping occurs within the reach between the Barham Lakes Caravan Park on the upstream side of the town and Hudson Creek on the downstream side of town.
- There are multiple locations between the Barham Lakes Caravan Park and the upstream limit of the model where overtopping of the NSW side levee bank or natural high ground line occurs. These overtopping flows inundate substantial areas whilst flowing northwards east of Barham, and also through parts of Barham.
- On the downstream side of Barham, overtopping occurs in the vicinity of Hudson Creek and also further downstream in the Cappelios Lane area. Extensive inundation occurs through much of the area to the north of Barham as a result of these overflows and also the flows originating from the overflow points upstream (south) of Barham.
- The difference between the modelled 100 year ARI flood level and the levee crest height where the overtopping occurs is generally quite small (less than 0.3 metres).

Records indicate that the Barham township area has not been subject to flooding in the largest events recorded since the mid 1950s (i.e. 1956, 1975, 1993). Some accounts refer to sandbagging in these events to prevent overtopping.

The 100 year ARI flood modelled is slightly larger than the 1956, 1975 and 1993 events. This is sufficient to generate the overtopping at various locations upstream and downstream of the township. Minimal raising of the levee banks at the overtopping locations (e.g. by less than 0.3 metres) would eliminate the overflows which are the cause of the extensive inundation in and around Barham shown on the 100 year ARI inundation maps.

Some breakaway flows discharge to the TUFLOW model's eastern boundary (as shown on Figure A1). Flooding conditions at the TUFLOW eastern boundary are sufficiently downstream not to impact on flood heights within the Barham town area. Consequently a uniform fixed boundary water level of 76.75 m AHD was used at these locations.

## 6.6 Sensitivity Assessment

### 6.6.1 Flow

The impact of a 20% increase and decrease in the 100 year ARI design flow was assessed using the TUFLOW hydraulic model to identify the sensitivity of the modelled flood levels to the flow rate.

The results are summarised in Table 4. Increasing the design flow by 20% from 35,900 ML/day to 43,000 ML/day will result in an increase in the modelled 100 year ARI flood levels by an average of 0.08 metres. Alternatively reducing the design flow by 20% from 35,900 ML/day to 28,700 ML/day will result in a decrease in the modelled 100 year ARI flow by an average of 0.18 metres.

The flow variations used for the sensitivity analysis are relatively extreme given the narrow range of flow conditions at Barham. The 100 year ARI adopted design flow at Barham is only 26% higher than the 5 year ARI design flow. The reasons for this are discussed earlier in the report. They relate primarily to the interaction of flows between the Murray River and its northern Edward / Wakool River anabranch system.

Table 4 Sensitivity of 100 Year ARI Flood Levels to Flow

| Location | Predicted change in 100 year ARI flood level (m) | |
|---|---|---|
| | 20% decrease in the 100 year ARI flow | 20% increase in the 100 year ARI flow |
| 4.7 km downstream of the Barham bridge (1) | -0.13 | +0.10 |
| 1.8 km downstream of the Barham bridge (3) | -0.14 | +0.08 |
| At the gauge on the downstream side of the Barham bridge (6) | -0.19 | +0.08 |
| 1.6 km upstream of the Barham bridge (7) | -0.24 | +0.08 |
| 3.2 km upstream of the Barham bridge (10) | -0.24 | +0.07 |
| 7.7 km upstream of the Barham bridge (16) | -0.19 | +0.06 |
| 9.9 km upstream of the Barham bridge (19) | -0.19 | +0.07 |
| 13.0 km upstream of the Barham bridge (20) | -0.16 | +0.08 |

### 6.6.2 Floodplain Roughness

The sensitivity of the modelled flood levels to the adopted Mannings roughness value was assessed using the hydraulic model. The calibrated Manning roughness values are documented in Section 6.4.

The hydraulic model was used to predict revised 100 year ARI flood levels based on the previously calibrated Mannings values reduced by 25% and increased by 25%. Results are summarised in Table 5.

A 25% increase in the Mannings roughness value results in an increase upstream of Barham of up to 0.08 metres. A 25% decrease in the Mannings roughness value results in a decrease upstream of Barham of up to 0.13 metres. The change in flood level towards the downstream end of the model is smaller due to the influence of the fixed downstream boundary water level.

Table 5 Sensitivity of 100 Year ARI Flood Levels to Floodplain Roughness

| Location | Predicted change in 100 year ARI flood level (m) | |
|---|---|---|
| | 25% decrease in Mannings roughness | 25% increase in Mannings roughness |
| 4.7 km downstream of the Barham bridge (1) | -0.02 | +0.01 |
| 1.8 km downstream of the Barham bridge (3) | -0.03 | +0.01 |
| At the gauge on the downstream side of the Barham bridge (6) | -0.06 | +0.02 |
| 1.6 km upstream of the Barham bridge (7) | -0.08 | +0.02 |
| 3.2 km upstream of the Barham bridge (10) | -0.09 | +0.03 |
| 7.7 km upstream of the Barham bridge (16) | -0.10 | +0.04 |
| 9.9 km upstream of the Barham bridge (19) | -0.12 | +0.07 |
| 13.0 km upstream of the Barham bridge (20) | -0.13 | +0.08 |

### 6.6.3 Bridge Blockage

The only bridge across the Murray River at Barham spans the full width of the Murray River channel. Consequently the afflux induced by the bridge is minimal even in large floods.

The sensitivity of the 100 year ARI flood levels to blockage of the bridge opening was assessed by assuming the bridge opening to be 20% blocked.

There was no modelled increase in flood level as a result of the bridge being 20% blocked (i.e. the increase is less than 0.01 metres).

The afflux at the bridge site is small. The 100 year ARI flood level at the bridge is 77.44 m AHD. The waterway area below this level after adjusting for the piers is 450 $m^2$. The average velocity of flow through the bridge opening is less than 1.0 m/s assuming zero blockage. The velocity through the bridge opening increases to 1.2 m/s if 20% blockage of the bridge waterway opening area is assumed. Given these very moderate velocities, negligible afflux would be expected through the bridge opening.

### 6.6.4 Downstream Boundary Water Level

To test the sensitivity of the upstream modelled flood levels to the assigned downstream boundary fixed water level condition, the downstream boundary water level was raised by 0.3 metre (i.e. from 76.75 to 77.05 m AHD). This is a very large increase given the relative insensitivity of flood levels to flows at Barham.

The resultant impact upstream was found to:

- Increase in flood height reduces to 0.13 metres 2 km downstream of the Barham bridge (i.e. on the downstream side of the town area).
- Increase in flood height reduces to 0.11 metres at the gauging station on the downstream side of the Barham bridge.
- Increase in flood height reduces to 0.05 metres upstream of the Barham Lakes Caravan Park (i.e. on the upstream side of town area).

### 6.6.5 Summary of Sensitivity Modelling Results

Even with the 20% increase in peak flow modelled (43,000 ML/day), flood level increases are limited to less than 0.1 metres. This is due to overflows overtopping the NSW side levee bank along the reach modelled. Any further increases in flood level within the river channel are minimal once this occurs.

The modelled flood levels with the 20% lower flow (i.e. 28,000 ML/day) are typically 0.2 metres lower. This is approximately the difference in water level expected based on the rating table at the gauging station.

The 100 year ARI flood heights are not particularly sensitive to the Manning roughness parameter values assigned. Main channel velocities are typically relatively low (e.g. 1.0 m/s) which limits the influence of the stream roughness.

The bridge waterway area at Barham is large, spanning the full width of the Murray River channel. The minimal afflux induced by the bridge is not therefore sensitive to blockage of up to 20%.

The downstream boundary water level assigned for the 100 year ARI modelling is considered to be quite reliable. It is based on recorded flood heights for large event flows (i.e. 1975) and has been adjusted taking into account the variation in stage discharge characteristics at the gauging station.

## 6.7 Discussion – Levee Modelling Approach

The following approach was adopted in regards to the hydraulic model defined levee conditions on the NSW side of the river at Barham:

- Levee crest heights defined in the hydraulic model coincide with the 2013 surveyed crest heights. Overtopping can therefore occur at any localised low points in the levee as per the levee height conditions at the time of the survey.
- The levees were not assumed to breach prior to the modelled flood level overtopping the levee crest or to fail (reduce in height) once overtopping occurred.

It could be argued that the above approach results in an outcome which suggests that Barham is less at risk of flooding than is actually the case. This argument is based on the assumption that the existing rural type levees, particularly the sections located upstream and downstream of the town area, are of a low standard, and consequently are likely to breach prior to the crest being overtopped and / or fail rapidly following overtopping. This scenario represents a worse scenario than that modelled.

An alternative argument can be put that the modelling approach adopted results in an outcome which suggests that Barham is more at risk of flooding than is actually the case.  This argument is supported by the following considerations:

- Levee breaches (i.e. failure prior to overtopping) resulting in flooding of Barham have not occurred in past floods (e.g. 1956, 1975, 1993).  This will in part be due to the typical low height of the levees due to the perched nature of the river channel.  The hydraulic pressure against the levee is therefore typically low thereby reducing the likelihood of a breach.
- The extremely slow rate of rise of floodwaters at Barham has in the past allowed sufficient time for localised topping up of any levee bank sections that have threatened to be overtopped.

The estimation of flood damages under existing conditions has not formed part of the current study.  It is expected that a Floodplain Risk Management Study (FRMS) will follow the completion of this Flood Study and that the FRMS will include the estimation of flood damages.

Careful consideration to the levee assumptions made will need to be given when assessing flood damages under existing conditions, including the NSW government guidelines for ‘Modelling Urban Levees for the Estimation of Flood Damages’.

# 7. Design Flood Modelling

## 7.1 Approach

The calibrated Mannings roughness parameter values were retained for the design flood modelling (refer Section 6.4).

Design flows were input into the hydraulic model as steady state flows given the slow rate of rise and fall recorded in past floods. The adopted design event flows derived from the flood frequency analysis of the gauged flows at Barham (refer Table 2) are as follows:

- 5 year ARI – 28,400 ML/day
- 10 year ARI – 31,100 ML/day
- 20 year ARI – 33,100 ML/day
- 50 year ARI – 34,900 ML/day
- 100 year ARI – 35,900 ML/day
- 200 year ARI – 37,500 ML/day

Fixed downstream boundary water levels were used for the above design events. The assigned boundary water levels are based on consideration of the calibration modelling results and the variation in stage versus discharge at the Barham gauging station. The fixed boundary water levels varied from 76.55 m AHD for the 5 year ARI event to 76.77 m AHD for the 200 year ARI event, consistent with the narrow flood height versus flow range at the gauging station.

## 7.2 Flood Map Outputs

A description of flood map outputs produced is provided in the following sections. The map outputs are included in Appendices A to D of this report.

### 7.2.1 Design Flood Extents and Flood Height Contour Series

Design flood extent and flood height contour mapping for the full range of design floods modelled is included in Appendix A. The flood height contours have been defined at 0.25 metres intervals. Mapping included in Appendix A consists of:

- 100 year ARI event – 0.25 metres interval flood height contours and flood extents:
  – Figure A1 - map covering the whole study area reach modelled (scale 1:50,000 at A3)
  – Figure A2 – map covering the existing and potential future town area only (scale 1:25,000 at A3)
- Further four design events - 0.25 metres interval flood height contours and flood extents covering the existing and potential future town area (scale 1:25,000 at A3)
  – Figure A3 – 5 year ARI
  – Figure A4 – 20 year ARI
  – Figure A5 – 200 year ARI
  – Figure A6 – Extreme event (three times the 100 year ARI event)

Given the pronounced compressed flow range at Barham, maps for the 10 and 50 year ARI events were not produced.

### 7.2.2 Hazard Category Map Series

The 2005 FDM provides the following definitions for the two floodplain hazard categories:

- High Hazard
  - '*Possible danger to personal safety, evacuation by trucks difficult, able-bodied adults would have difficulty in wading to safety, potential for significant structural damage to buildings.*'
- Low Hazard
  - '*Should it be necessary, truck could evacuate people and their possessions, able-bodied adults would have little difficulty in wading to safety*.'

The provisional hazard categories have been identified based on hydraulic conditions coinciding with the 100 year ARI flood. This has been determined in accordance with Figure L2 of the 2005 FDM (reproduced in Figure 7 below).

Hazard mapping included in Appendix B is as follows:

- Figure B1 – 100 year ARI event
- Figure B2 – 20 year ARI event

The provisional hazard categories should be reviewed at the time of a Floodplain Risk Management Study taking into account other factors aside from the depth and velocity of floodwaters (e.g. effective warning time, flood readiness, rate of rise of floodwaters, duration of flooding, evacuation problems and flood access considerations).

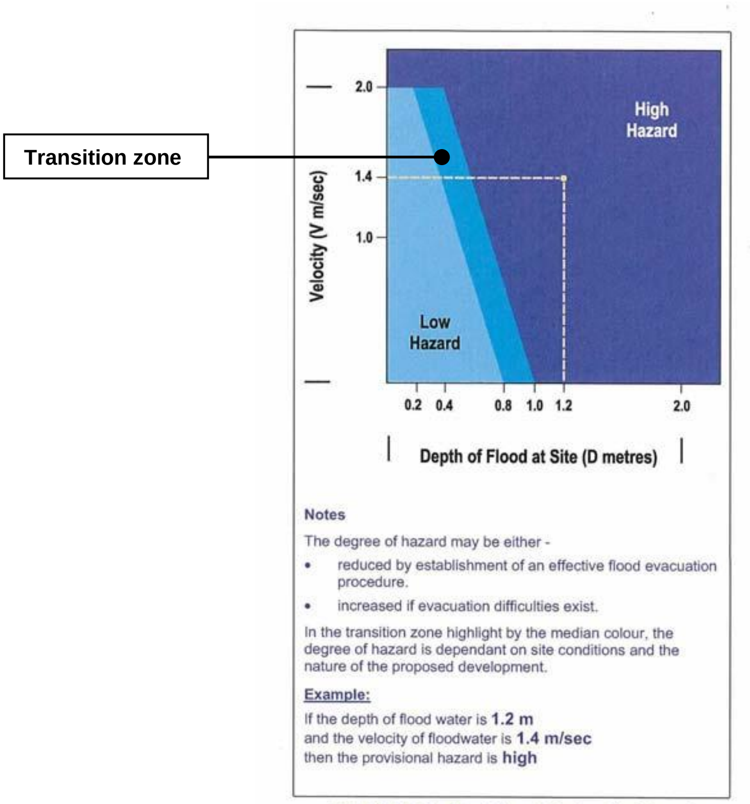



*FIGURE L2 - Provisional Hydraulic Hazard Categories*

Figure 7 2005 FDM Hazard Categories

(extract from 2005 FDM)

### 7.2.3 Hydraulic Category Map Series

The 2005 FDM defines three hydraulic categories as follows:

- Floodways
  - '*Those areas where a significant volume of water flows during floods and are often aligned with obvious natural channels. They are areas that, even if only partially blocked, would cause a significant increase in flood levels and / or a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocity occurs*.'
- Flood Storage
  - *'Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.'*
- Flood Fringe
  - *'The remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and / or flood levels.'*

Explicit quantitative criteria for defining the above three hydraulic categories are not provided by the 2005 Manual or the 2007 DECC Guideline for Floodway Definition. The 2005 Manual nominates a guideline which defines flood storage areas as those areas which, if completely filled with solid material, would cause peak flood levels to increase anywhere more than 0.1 m and / or would cause the peak discharge anywhere downstream to increase by more than 10%. The 2007 DECC Guideline nominates that the obstruction of a floodway would lead to either the significant diversion of water away from its existing flow path and / or lead to a significant increase in flood levels.

Recent studies have made use of criteria identified within a technical paper (Howells et al, 2004) as the basis for the hydraulic categorisation. These criteria have been used to produce the hydraulic category mapping at Barham presented in Appendix C. The approach uses the following criteria for the delineation of the floodway:

- Velocity depth product must be greater than 0.25 $m^2/s$ and the velocity must be greater than 0.25 m/s, or
- Velocity is greater than 1.0 m/s

Outside the above defined floodway area, flood storage was defined as those areas where the depth exceeds 0.5 metres. The remaining inundated area was defined as flood fringe.

The hydraulic categorisation mapping provided in Appendix C is as follows:

- Figure C1 – 100 Year ARI event
- Figure C2 – 20 Year ARI event

### 7.2.4 Design Event Profile Map Series

The flood height contours represent the flood height surface gradient. Flood profiles present the same information plotted on a longitudinal section.

The design flood profile plotted relative to the river route is presented on Figure D1 in Appendix D.

### 7.2.5 Flood Planning Area

The flood planning area is the area of land below the flood planning level (FPL) which is consequently subject to flood related development controls (e.g. minimum floor level requirements). The FPLs are the combination of flood levels and freeboards selected for floodplain risk management purposes. This typically amounts to the 100 year ARI flood levels plus a freeboard provision. A freeboard of 500 mm is commonly adopted. The FPLs are generally adopted during a floodplain risk management study.

Figure A1 includes an extent line 500 mm above the adopted 100 year ARI flood levels. The area encompassed by the 500 mm extent line would represent the flood planning area assuming that the FPLs are based on the 100 year ARI flood levels plus a freeboard provision of 500 mm.

## 7.3 Discussion Modelled Flooding Results

Previous discussion in regards to the 100 year ARI modelled flooding conditions are provided in Sections 6.5 and 6.7. Some further more detailed descriptions are provided as follows.

### 7.3.1 General

The Murray River channel at Barham is perched (refer to Figure 4). Ground levels fall away from the river channel on both the Victorian and NSW sides of the river. Levees banks have generally been constructed in close proximity to the river banks within the higher ground area. The banks are consequently not very high and in some reaches there is no man made bank given the naturally high ground present.

Murray River flood levels at Barham are relatively insensitive to the upstream flow passing Echuca. The river channel past Barham has an upper limiting flow in the vicinity of 36,000 ML/day due to the capacity of the Barbers Creek / Wakool River floodplain system to accommodate higher flows.

As a consequence of the above characteristics, the levee system paralleling the NSW side of the river channel for the Barham reach has generally been constructed such that there is very little freeboard in major flood events. The slow rising nature of flooding at Barham allows for the topping up of levee segments where overtopping threatens to occur, as has occurred in past major floods (e.g. 1993, 1975, 1956).

The modelling undertaken as part of this flood study is based on existing levee crest heights. The modelling has identified overtopping occurring at some points in the levee system. This was largely inevitable given the informal nature of most of the levee system upstream and downstream of Barham, the little or no freeboard provision in the levee and the tendency for parts of a rural standard levee system to settle or have the crest height reduced due to stock or vehicle movements. Additionally there have been no large floods at Barham since 1993 and sections of rural levee upstream of Barham are likely to have settled marginally. There has been little motivation for landholders to top up any levee segments which have settled given the absence of large floods since 1993.

On the basis of the 2013 surveyed levee crest heights, the mapping prepared therefore shows widespread inundation in the area around Barham. This has not occurred in any of the more recent major floods due to either the flood being smaller than the 100 year ARI design event, or as a result of the topping up of any sections of levee bank that threaten to overtop. The slow rate of rise of floodwater at Barham has in the past allowed sufficient time for topping up of levees where this has needed to be done.

The hydraulic modelling indicates there is no overtopping of the levee bank system at Barham itself (refer to Figure 8). This includes the Eagle Creek Cutting where a flood gate at the river end confines floodwater.

The nearest point upstream of Barham where overtopping is predicted to occur is located south of the Barham Lakes Caravan Park as shown on Figure 8. These overtopping flows discharge northwards into the upper reaches of Eagle Creek. Flow also discharges north westwards across the Eagle Creek Cutting and into the town area. It is expected that in an event equivalent to a 100 year flood, low level sandbagging or temporary earth banks less than 0.3 metres high would be sufficient to prevent floodwater entering the town from the East Barham Road / Eagle Creek Cutting direction.

The focus of this study is on the Barham side of the Murray River. As such, considerable effort has been made to accurately define the levee crest heights on this side of the river (i.e. through the levee crest height survey commissioned as part of this study). The levee crest heights on the Victorian side have been assumed to be sufficiently high to confine floodwaters. The flooding conditions modelled on the Victorian side of the river may not therefore entirely reflect existing conditions and / or be affected by the limitations of the accuracy of the LiDAR data.

Overtopping further upstream in a 100 year ARI event is expected to occur at the locations shown on Figure 8. Topping up of levee banks at these locations would prevent this occurring. Once overtopping occurs, the floodwater discharges northwards resulting in the widespread inundation shown on the 100 year ARI flood extent map (refer to Figures A1 and A2).

Downstream of Barham, flooding conditions are quite complex. The modelling indicates that the levee will overtop approximately 1 km north of Hudson Creek. Backwater flooding will then overtop the North Barham Road at and south of the Hudson Creek crossing. The backwater inundation will affect the low lying northern parts of Barham.

### 7.3.2 Impacts on Existing Development

As described in the preceding section, a major factor which has allowed the township of Barham to escape relatively unscathed from river flooding in the previous 100 years is a combination of the levee system which has been in place for that period and the slow rate of rise of floodwaters. Although the levee system is not of a standard which is consistent with design and construction standards for modern urban levees, it has been possible to strengthen and top up the levee where needed in large floods such as the 1956, 1975 and 1993 floods.

Past flooding impacts on the town have therefore been minimal. This is likely to continue unless the levee system in place deteriorates substantially.

Current flood risks at Barham have been further reduced as a result of the recent construction of the perimeter levee bank around the Koondrook-Pericoota Forest to the east of Barham. Although the bank has been constructed to allow for confined environmental watering of the forest, it acts as a defacto levee bank in a natural flood event. The recently constructed high standard bank (refer to Photograph 4) replaces the previous lower rural standard levee bank.

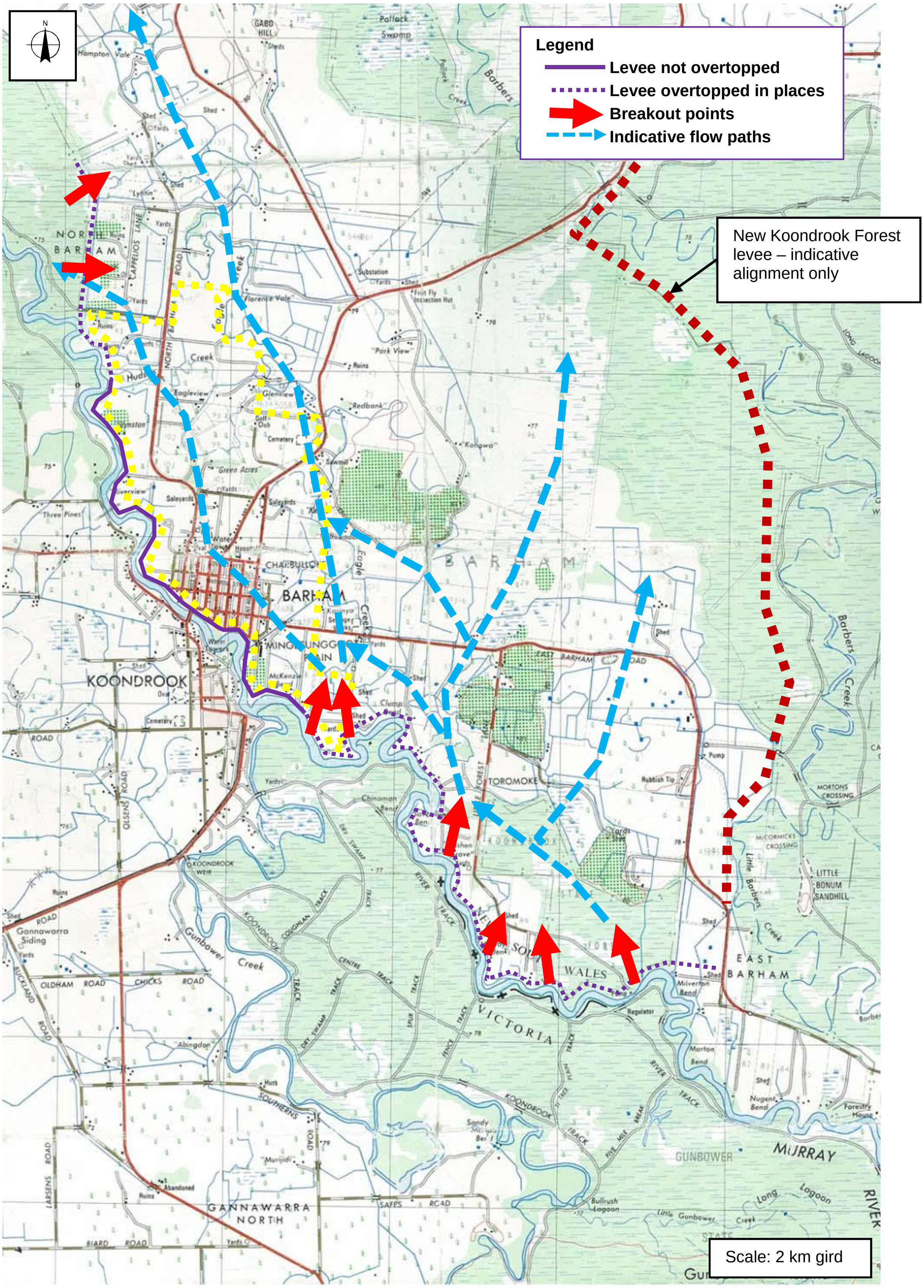



Figure 8 Prominent Flows Paths Once Levees Overtopped

As described in the previous section, it was inevitable that localised sections of the rural levee system upstream of Barham would be overtopped given the hydraulic model uses the 2013 surveyed levee crest heights.  This results in widespread shallow inundation as the overtopping floodwater discharges northwards.  Parts of Barham potentially affected by inundation are shown on Figures A1 and A2.  The inundation is generally shallow (i.e. typically less than 0.2 metres).  Buildings with floor levels close to ground level will however be vulnerable to above floor flooding.

The estimation of flood damages has not formed part of this study.  The estimation of flood damages requires the comparison of building floor level elevations with design flood levels and the subsequent use of flood damage curves.

#### 7.3.3 Future Development – Issues

Barham has considerable potential for growth.  An extract from the Land Use Strategy Report (Collie, 2009) presented as Figure 9 shows the potential future development areas at Barham.

A comparison of the areas shown on Figure 9 with Council's Local Environment Plan (LEP) 2013 confirms that most of the future growth areas earmarked by the 2009 report are now zoned such that development can proceed in these areas.

Comments in regards to flood related risks and issues for the future development areas are provided as follows (refer to Figure 9 and Figure A2):

- Area 1 – south of East Barham Road (zoned General Residential).  Provisional classification – Low Hazard (from Figure B1) and predominantly Flood Fringe (from Figure C1).   Relies on existing rural standard levee for protection.  Current modelling indicates localised levee overtopping in 100 year ARI flood resulting in shallow inundation as shown on Figure A2.
- Area 2 – Jamieson Avenue (zoned Large Lot Residential).  Provisional classification – not affected by 100 year ARI inundation.  Relies on existing rural standard levee for protection.
- Area 3 – east end of Gonn Street (zoned General Residential).  Provisional classification – Low Hazard and Flood Fringe.  Inundation as shown on Figure A2 associated with overtopping of the levee system upstream of Barham.
- Area 4 – area adjoining Eagle Creek (zoned Large Lot Residential).  Provisional classification – predominantly Low Hazard and Flood Fringe.  Inundation as shown on Figure A2 associated with overtopping of the levee system upstream of Barham spilling into Eagle Creek.
- Area 5 – northern end of Teddys Place estate and adjoining north side property (zoned General Residential).  Provisional classification – predominantly Low Hazard and Flood Fringe with some Flood Storage.  Inundation as shown on Figure A2 associated with overtopping of the levee system upstream of Barham.
- Area 6 – area north and west of Eagle Street (zoned Primary Production).  Provisional classification – Low Hazard and Flood Fringe.  Partly affected by inundation as shown on Figure A2 associated with overtopping of the levee system upstream of Barham.
- Area 7 – area north of Lawson Street (zoned Large Lot Residential).  Provisional classification – Low Hazard and predominantly Flood Fringe.   Inundation as shown on Figure A2 associated with overtopping of the levee system upstream of Barham.

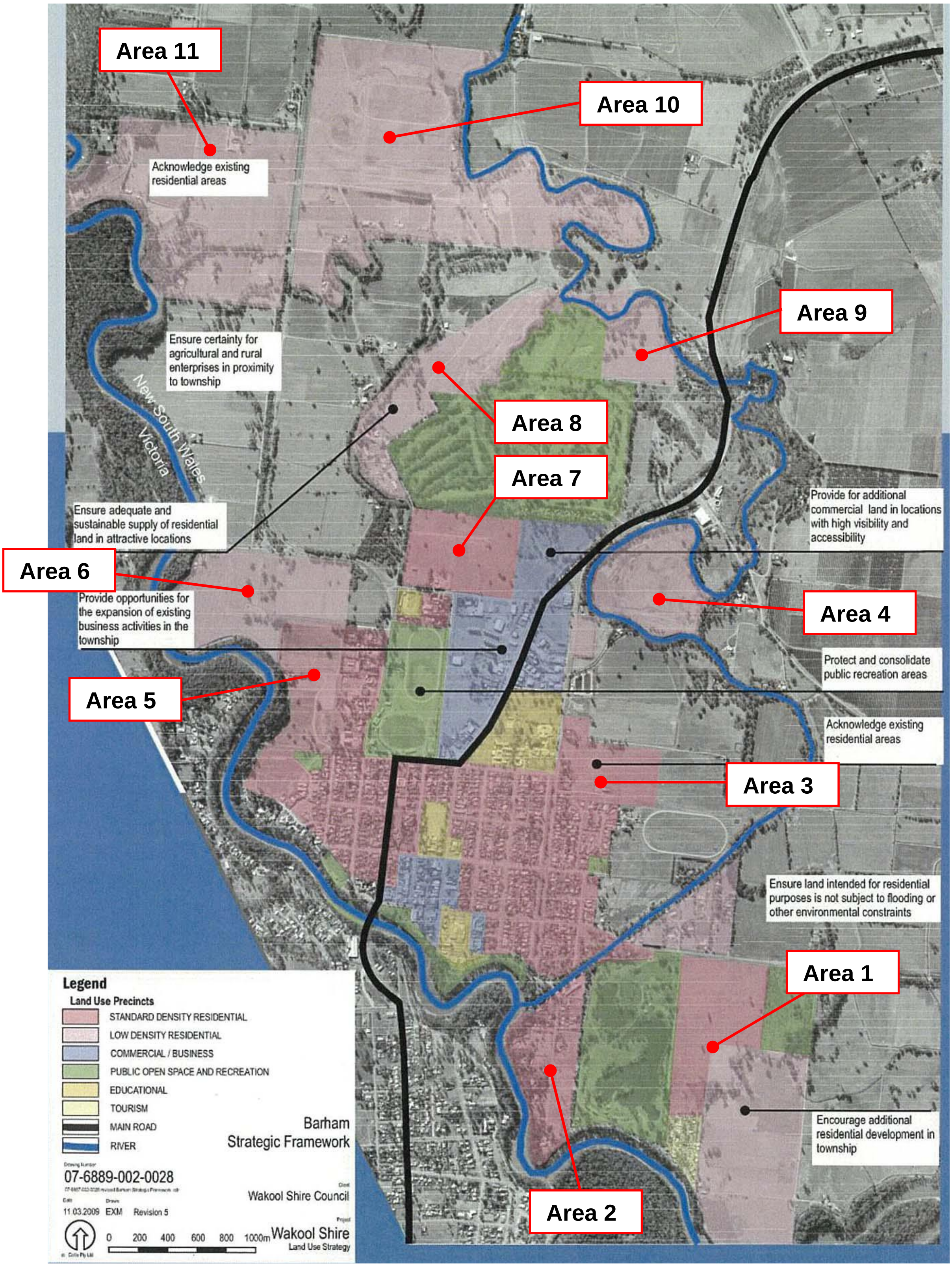



Figure 9 Potential Future Land Use Development Areas at Barham

(modified extract from 2009 Land Use Strategy Report

- Area 8 – area adjoining the Golf Course and the Hudson Creek watercourse (zoned Large Lot Residential). Provisional classification – predominantly Low Hazard and varying hydraulic category conditions. Inundation as shown on Figure A2 associated with overtopping of the levee system upstream of Barham, backwater flooding from Eagle Creek up Hudson Creek.
- Area 9 – between Eagle Creek and the Golf Course (zoned Primary Production). Provisional classification – predominantly Low Hazard and mixture Flood Storage and Flood Fringe. Inundation as shown on Figure A2 associated with overtopping of the levee system upstream of Barham.
- Area 10 – east side of North Barham Road – Glenview Road estate (zoned Large Lot Residential). Provisional classification – varying hazard and hydraulic category conditions. Parts of this area are subject to 100 year ARI inundation as shown on Figure A2. Contributing factors overtopping of the levee system upstream of Barham, backwater flooding and backwater flooding effects up Eagle Creek and Hudson Creek.
- Area 11 – west side of North Barham Road opposite the Glenview Road estate (zoned Large Lot Residential). Provisional classification – predominantly Low Hazard and mixture Flood Fringe and Flood Storage. Backwater flooding area due to overtopping of the downstream rural levee system.

As previously indicated, most of the flooding on the above areas is due to overtopping of the rural levee system upstream of Barham. This is generally localised and peaking less than 0.3 metres above the 2013 surveyed levee crest height. In previous large floods (e.g. 1956, 1975, 1993), topping up of the levee system has prevented the levee system being overtopped. Flooding as depicted in Figures A1 and A2 has not therefore been experienced at Barham since at least 1917.

## 7.4 Flood Data at Points of Interest

Detailed hydraulic model output is provided in Table 4 at particular points of interest within the study area floodplain. This data is provided to assist with flood response plans. The data is generally based on modelled predictions as distinct from actual recorded observations in past flood events. There may therefore be some differences between actual flood conditions encountered in future floods and the modelled data given in Table 4.

It is stressed that the levee system downstream and upstream of Barham generally has very little freeboard. With the absence of a major flood since 1993, there has not been any compelling reason for landholders to top up sections of levee which may have marginally subsided. The modelling results in this study are based on surveyed levee crest heights in September 2013.

Flooding at Barham may also occur at lower thresholds due to a major breach in part of the levee system. The levees upstream and downstream of Barham are of a lower standard than modern urban levees and breaching is a possible scenario. Generally the levees are low level banks in terms of their height which reduces the hydraulic pressure on the levee bank and therefore limits the risk of a breach. Major levee breaches have not occurred in previous floods, however this cannot be assumed for future floods.

Table 4 Flood Data – Points of Interest

| Location | Overtopping Threshold | | | 100 Year ARI Depth Overtopping (m) | Indicative Duration Overtopping |
|---|---|---|---|---|---|
| | Flow (ML/day) | ARI (years) | Barham gauge height (m) | | |
| Moulamein Road at Eagle Creek | 33,000 | 20 | 6.13 | < 0.2 | 1 to 7 days |
| East Barham Road at Little Forest Lane | 33,000 | 20 | 6.13 | < 0.2 | 1 to 7 days |
| North Barham Road south of Hudsons Creek | 35,000 | 50 | 6.17 | < 0.1 | 1 to 7 days |

Note:

1. Gauge zero datum at the Barham gauging station site is 71.28 m AHD.

# 8. Next Steps in Process

This flood study represents the first step in the process set out by the NSW Floodplain Development Manual (2005) leading to the preparation of a Floodplain Management Plan. The second step of the process requires a Floodplain Risk Management Study (FRMS) to be carried out. The FRMS assesses options for managing the flood risk to existing and future development including flood modification works (e.g. levee banks), property modification measures (e.g. land use planning controls) and response modification measures (e.g. better ways to prepare, respond and recover from floods).

In regards to Barham, the major issues to be addressed by a future FRMS will include:

- Future arrangements associated with any possible upgrades to and ongoing maintenance of the levee system both adjoining the town, and upstream and downstream of the town.
- An assessment of flood related land use planning and development controls appropriate for Barham including the adoption of the Flood Planning Area and Flood Planning Levels.
- Refinement of the flood hazard and hydraulic category mapping taking into account factors aside from the depth and velocity of floodwaters (e.g. effective warning time, rate of rise of floodwaters, duration of flooding, evacuation considerations etc).

# 9. Acknowledgments

GHD has completed the Barham, Murray Downs and Tooleybuc Flood Study project with the assistance of the Wakool Shire Council's Floodplain Risk Management Committee, Council's staff, Office of Environment of Heritage's staff and the other government agency and local residents who have had involvement in the project. The assistance which has been provided is very much appreciated by both GHD and the Wakool Shire Council.

The Wakool Shire Council has prepared this document with financial assistance from the NSW and Commonwealth Governments through the Natural Disaster Resilience Program. This document does not necessarily represent the opinions of the NSW or Commonwealth Governments.

# 10. Glossary

**Annual Exceedance Probability (AEP)** - AEP (measured as a percentage) is a term used to describe flood size. AEP is the long-term probability between floods of a certain magnitude. For example, a 1% AEP flood is a flood that occurs on average once every 100 years. It is also referred to as the '100 year flood' or 1 in 100 year flood'.

0.5% AEP sometimes referred to as the 1 in 200 year ARI event

1% AEP sometimes referred to as the 1 in 100 year ARI event

2% AEP sometimes referred to as the 1 in 50 year ARI event

5% AEP sometimes referred to as the 1 in 20 year ARI event

10% AEP sometimes referred to as the 1 in 10 year ARI event

20% AEP sometimes referred to as the 1 in 5 year ARI event

**Afflux** - The increase in flood level upstream of a constriction of flood flows. A road culvert, a pipe or a narrowing of the stream channel could cause the constriction.

**Australian Height Datum (AHD)** - A common national plane of level approximately equivalent to the height above sea level. All flood levels; floor levels and ground levels in this study have been provided in meters AHD.

**Average annual damage (AAD)** - Average annual damage is the average flood damage per year that would occur in a nominated development situation over a long period of time.

**Average recurrence interval (ARI)** - ARI (measured in years) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 100-year ARI flood is a flood that occurs or is exceeded on average once every 100 years.

**Catchment** - The land draining through the main stream, as well as tributary streams.

**Critical Duration** – The storm duration at which the peak flood flow and/or flood level occurs

**Development Control Plan (DCP**) - A DCP is a plan prepared in accordance with Section 72 of the *Environmental Planning and Assessment Act, 1979* that provides detailed guidelines for the assessment of development applications.

**Design flood level** - A flood with a nominated probability or average recurrence interval, for example the 100 year ARI flood is commonly use throughout NSW.

**OEH (formerly DECCW, DECC, DNR, DLWC, DIPNR)** - Office of Environment and Heritage. Covers a range of conservation and natural resources science and programs, including native vegetation, biodiversity and environmental water recovery to provide an integrated approach to natural resource management. The NSW State Government Office provides funding and support for flood studies.

**Discharge** - The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s) or megalitres per day (ML/day). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving.

**Effective warning time** - The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

**Extreme flood** - An estimate of the probable maximum flood (PMF), which is the largest flood likely to occur.

**Flood** - A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

**Flood awareness** - An appreciation of the likely effects of flooding and knowledge of the relevant flood warning, response and evacuation procedures.

**Flood Fringe** - The remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and / or flood levels.'

**Flood hazard** - The potential for damage to property or risk to persons during a flood. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.

**Flood level** - The height of the flood described either as a depth of water above a particular location (e.g. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (e.g. the flood level was 77.5 m AHD). Terms also used include flood stage and water level.

**Flood liable land** - Land susceptible to flooding up to the Probable Maximum Flood (PMF). Also called flood prone land. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the superseded Floodplain Development Manual (NSW Government, 2005).

**Flood Planning Levels (FPLs)** - The combination of flood levels and freeboards selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies.

**Flood Prone Land** - Land susceptible to flooding up to the Probable Maximum Flood (PMF). Also called flood liable land.

**Flood stage** - see flood level.

**Flood Storage -** Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.

**Flood Study** - A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.

**Floodplain** - The area of land that is subject to inundation by floods up to and including the Probable Maximum Flood event, that is, flood prone land or flood liable land.

**Floodplain Risk Management Study** – Studies carried out in accordance with the Floodplain Development Manual and assess options for minimising the danger to life and property during floods.

**Floodplain Risk Management Plan -** The outcome of a Floodplain Management Risk Study.

**Floodway** - Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

**Freeboard** - A factor of safety expressed as the height above the design flood level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as "greenhouse" and climate change.

**High Flood Hazard** - For a particular size flood, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.

**Hydraulics Term** - given to the study of water flow in waterways, in particular, the evaluation of flow parameters such as water level and velocity.

**Hydrology Term** - given to the study of the rainfall and runoff process; in particular, the evaluation of peak discharges, flow volumes and the derivation of hydrographs (graphs that show how the discharge or stage/flood level at any particular location varies with time during a flood).

**Local catchments** - Local catchments are river sub-catchments that feed river tributaries, creeks, and watercourses and channelised or piped drainage systems.

**Local Environmental Plan (LEP)** – A Local Environmental Plan is a plan prepared in accordance with the *Environmental Planning and Assessment Act*, 1979, that defines zones, permissible uses within those zones and specifies development standards and other special matters for consideration with regard to the use or development of land.

**Local overland flooding** - Local overland flooding is inundation by local runoff within the local catchment.

**Local runoff -** local runoff from the local catchment is categorised as either major drainage or local drainage in the NSW Floodplain Development Manual, 2005.

**Low flood hazard** - For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.

**Flows or discharges** - It is the rate of flow of water measured in terms of volume per unit time.

**Overland flow path -** The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as 'overland flows', may or may not re-enter the main channel from which they left — they may be diverted to another watercourse.

**Peak discharge -** The maximum flow or discharge during a flood.

**Probable Maximum Flood (PMF)** - The largest flood likely to ever occur. The PMF defines the extent of flood prone land or flood liable land, that is, the floodplain.

**Risk** - Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

**Runoff -** the amount of rainfall that ends up as flow in a stream, also known as rainfall excess.

**SES -** State Emergency Service of New South Wales.

**Stage–damage curve** - A relationship between different water depths and the predicted flood damage at that depth.

**Velocity** - the term used to describe the speed of floodwaters, usually in m/s (metres per second). 10km/h = 2.7m/s.

**Water surface profile -** A graph showing the height of the flood (flood stage, water level or flood level) at any given location along a watercourse at a particular time.

# 11. References


Collie, Ivey, Geolyse and Groupwork (April 2009). Wakool Shire LEP review – Land Use Strategy Report. Prepared for Wakool Shire Council.

Department of Environment Climate Change and Water (January 2011). *Floodplain Management Plan – Wakool River Stage 2 – Moama-Moulamein Railway to Gee Gee Bridge*.

Department of Land and Water Conservation Specialist Coastal and Flood Serrvices Branch (July 2000). *Edward and Wakool Rivers Floodplain Management Strategy – Noorong Road to Wakool Murray Junction*. Prepared for NSW Department of Land and Water Conservation.

Egis Consulting (May 2000). *Flood Data Transfer Project – River Basin Report – Murray River Basin*. Prepared for the Department of Natural Resources and Environment.

Egis Consulting (May 2000). *Flood Data Transfer Project – Rural City of Swan Hill Report*. Prepared for the Department of Natural Resources and Environment.

GHD (July 2011). *Riverlife Estate, Barham – Flood Risk Assessment*. Prepared for Riverlife Property Group.

GHD (March 2011). *Lots 14, 15 and 16 – DP 1039025, Yarrein Street, Barham – Flood Risk Management Plan*. Prepared for Sundance Resort Pty Ltd.

Gutteridge Haskins & Davey, Cameron McNamara, and Lawrie Montgomerie & Pettit (December 1998). Murray River Flood Plain Management Study. Both a 'Summary Report', a 'Detailed Report', and a 'Flood Plain Atlas' prepared for the Rural Water Commission of Victoria and the Water Resources Commission of NSW.

Gutteridge Haskins & Davey (February, 1995). *Barham Town Levee Investigation*. Prepared for Wakool Shire Council.

Rural Water Commission of Victoria (1990). *Victorian Water Surface Information to 1987 – Volume 4.*

Wakool Shire Council (1997). Local Disaster Plan (Displan)

Wakool Shire Council (December 2007). *Shire of Wakool Local Flood Plan.* A sub-plan of the Wakool Shire Local Disaster Plan.

# Appendices

# Appendix A – Design Flood Maps

**Notes/Limitations**

1. The flood levels on this plan may be exceeded by more severe floods.

2. The derivation of the flood levels and extent has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.

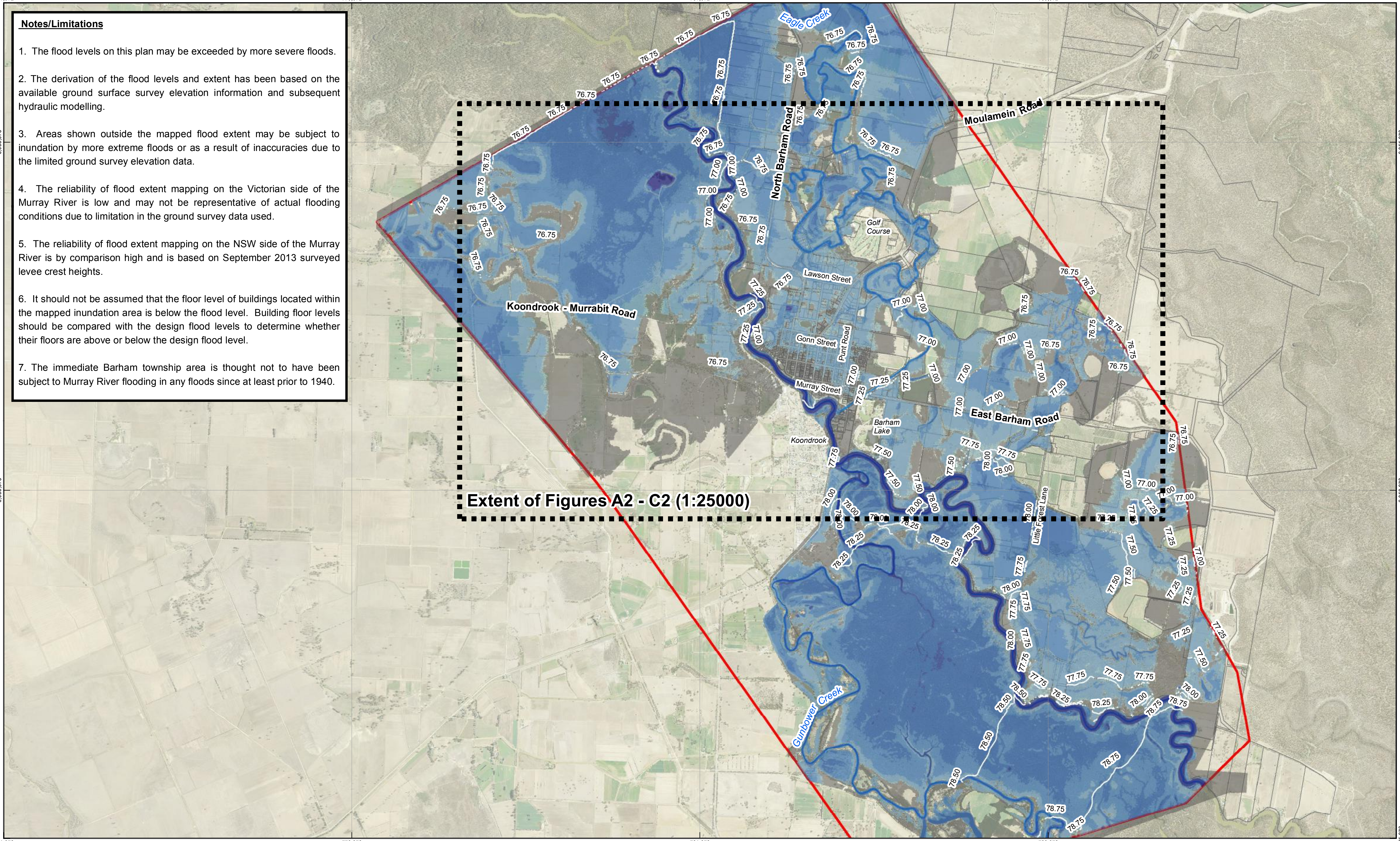
3. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods or as a result of inaccuracies due to the limited ground survey elevation data.

4. The reliability of flood extent mapping on the Victorian side of the Murray River is low and may not be representative of actual flooding conditions due to limitation in the ground survey data used.

5. The reliability of flood extent mapping on the NSW side of the Murray River is by comparison high and is based on September 2013 surveyed levee crest heights.

6. It should not be assumed that the floor level of buildings located within the mapped inundation area is below the flood level. Building floor levels should be compared with the design flood levels to determine whether their floors are above or below the design flood level.

7. The immediate Barham township area is thought not to have been subject to Murray River flooding in any floods since at least prior to 1940.




Paper Size A3

0 250 500 1,000 1,500 2,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

**Flood Extent and Depth (m)**

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00

- Flood Level Contours (mAHD)
- 100 Year ARI + 0.5m
- Hydraulic Model Extents
- Cadastre

GHD | WAKOOL SHIRE COUNCIL

Wakool Shire Council
Barham Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

100-Year ARI Flood Event
Flood Extent and Depth

Figure A1

G:\31\30143\GIS\Maps\Deliverables\Barham\31_30143_WSC_Barham_FS_Figure_A1_Rev_0.mxd

180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com



Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

**Notes/Limitations**

1. The flood levels on this plan may be exceeded by more severe floods.

2. The derivation of the flood levels and extent has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.

3. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods or as a result of inaccuracies due to the limited ground survey elevation data.

4. The reliability of flood extent mapping on the Victorian side of the Murray River is low and may not be representative of actual flooding conditions due to limitation in the ground survey data used.

5. The reliability of flood extent mapping on the NSW side of the Murray River is by comparison high and is based on September 2013 surveyed levee crest heights.

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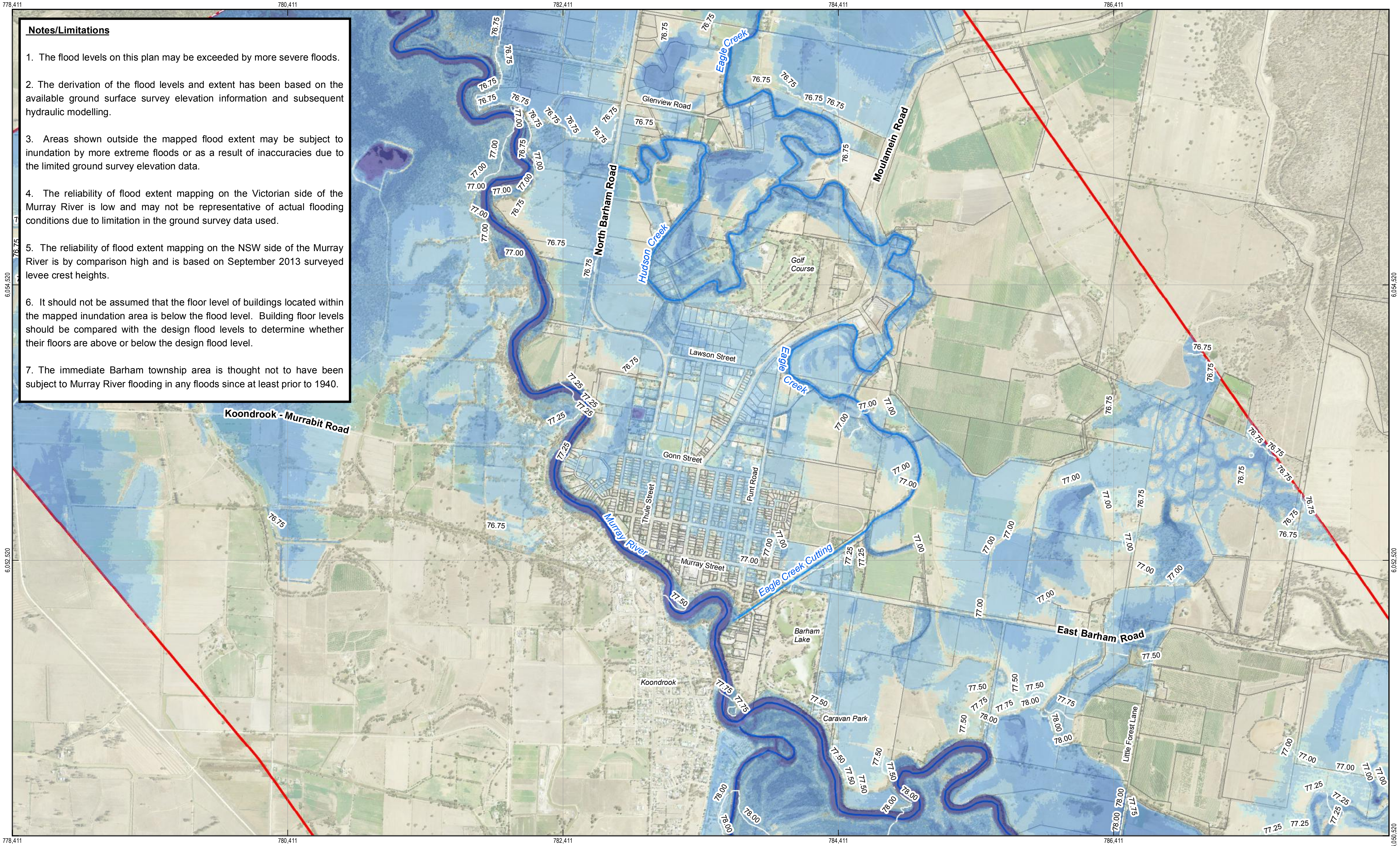


Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

**Flood Extent and Depth (m)**

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00
- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

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Wakool Shire Council
Barham Flood Study

| | |
|---|---|
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| Date | 07 Oct 2014 |

100-Year ARI Flood Event
Flood Extent and Depth

Figure A2

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com



Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

**Notes/Limitations**

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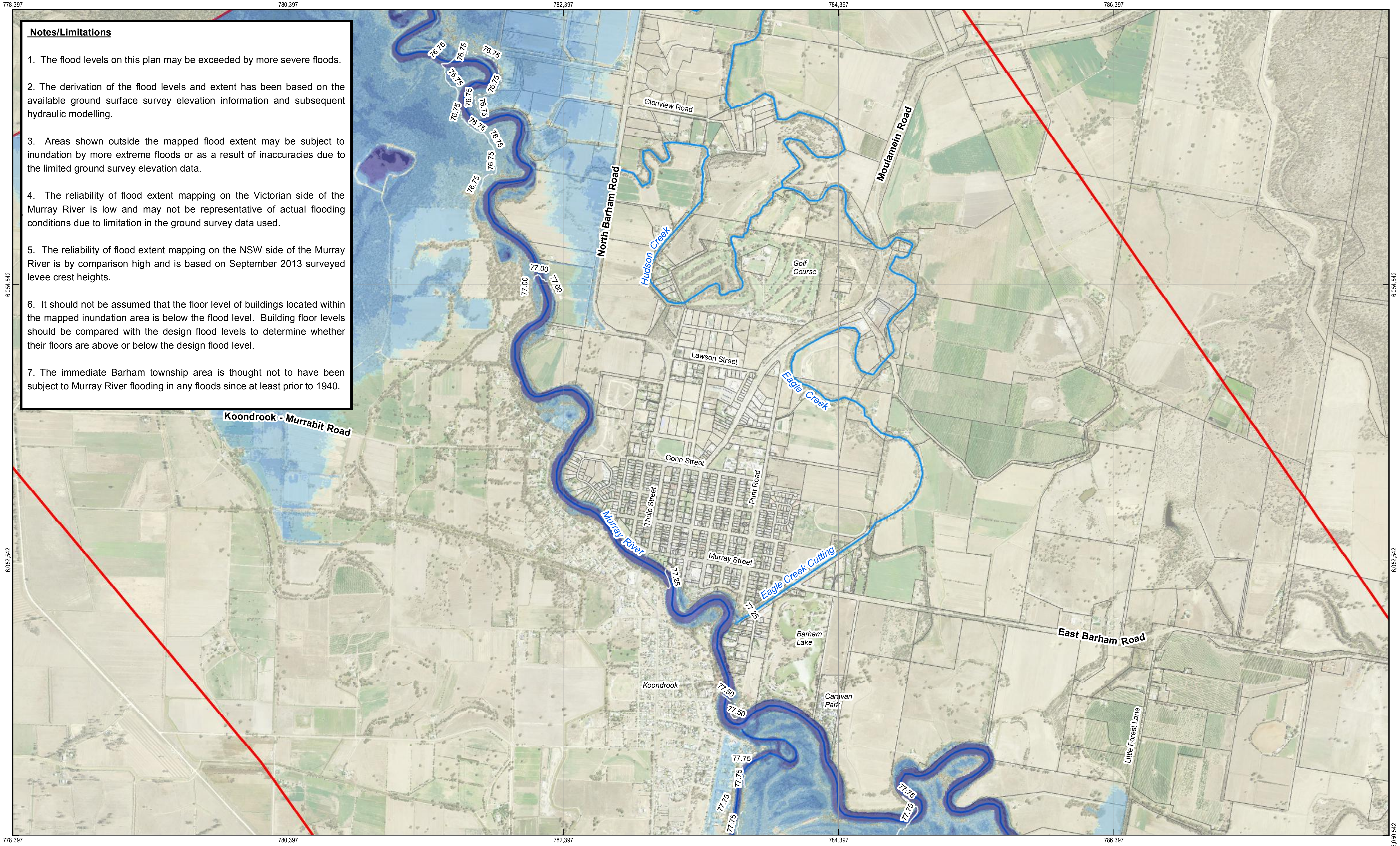


Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

**Flood Extent and Depth (m)**

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00
- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

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Barham Flood Study

| Job Number | 31-30143 |
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| Date | 07 Oct 2014 |

5-Year ARI Flood Event
Flood Extent and Depth

Figure A3

G:\31\30143\GIS\Maps\Deliverables\Barham\31_30143_WSC_Barham_FS_Figure_A3_Rev_0.mxd

180 Lonsdale Street Melbourne VIC 3000 Australia **T** 61 3 8687 8000 **F** 61 3 8687 8111 **E** melmail@ghd.com **W** www.ghd.com



Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# Notes/Limitations

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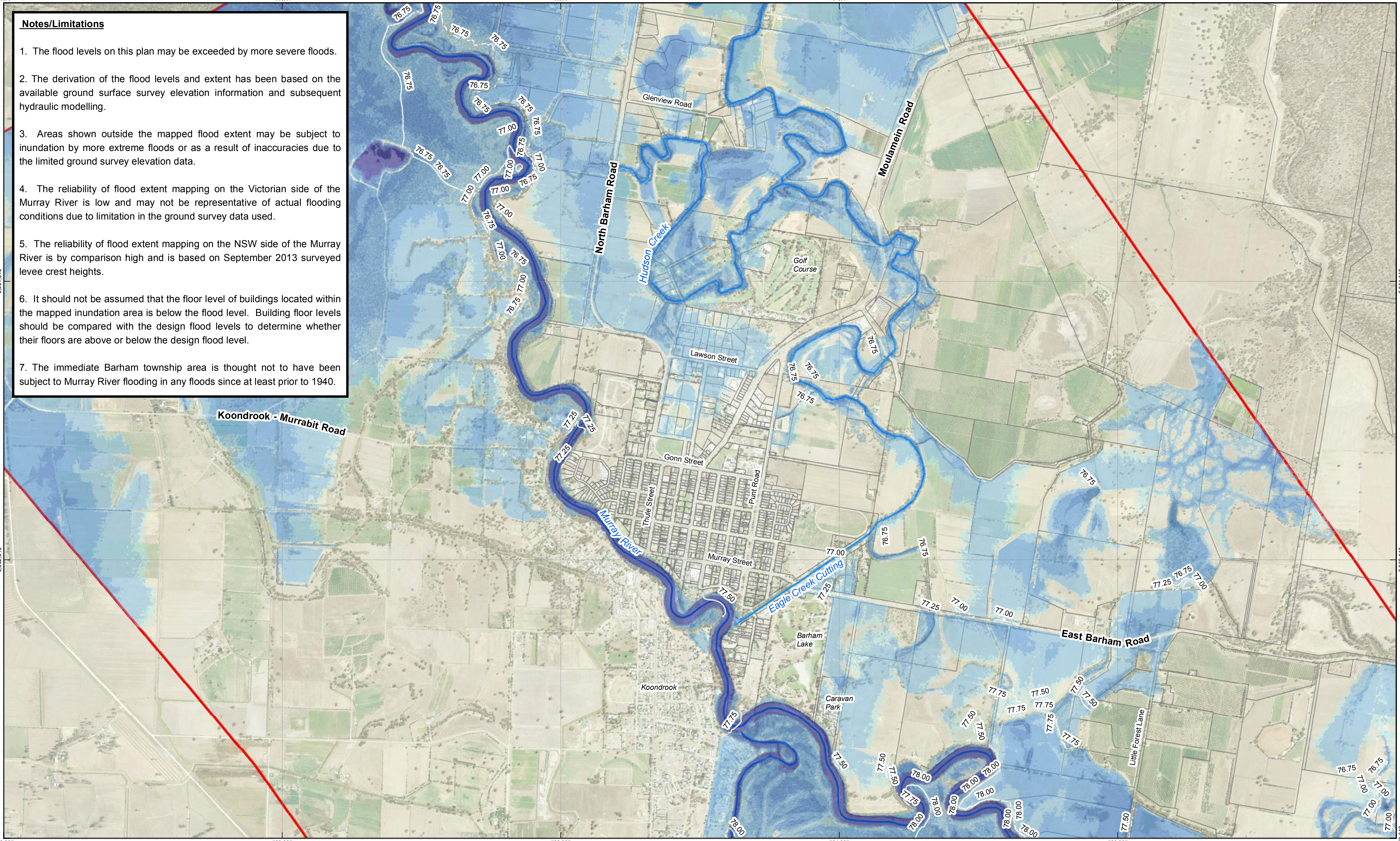


Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

Flood Extent and Depth (m)

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00

Flood Level Contours (mAHD)

Hydraulic Model Extents

Cadastre

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Barham Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
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## 20-Year ARI Flood Event
## Flood Extent and Depth

Figure A4

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Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

**Notes/Limitations**

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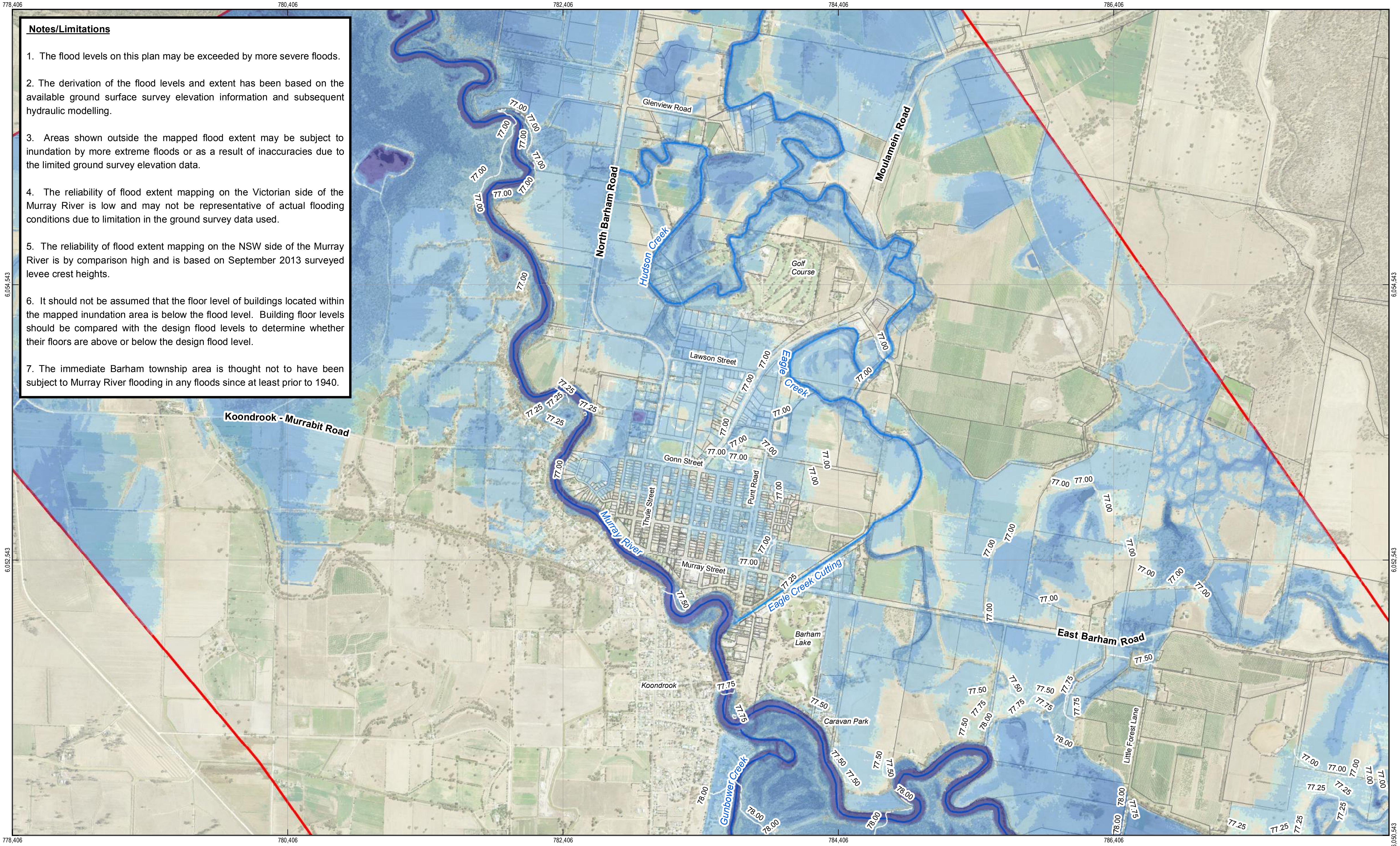


## Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

## Legend

**Flood Extent and Depth (m)**

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00

- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

GHD

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| Revision | 0 |
| Date | 07 Oct 2014 |

# 200-Year ARI Flood Event
# Flood Extent and Depth

**Figure A5**

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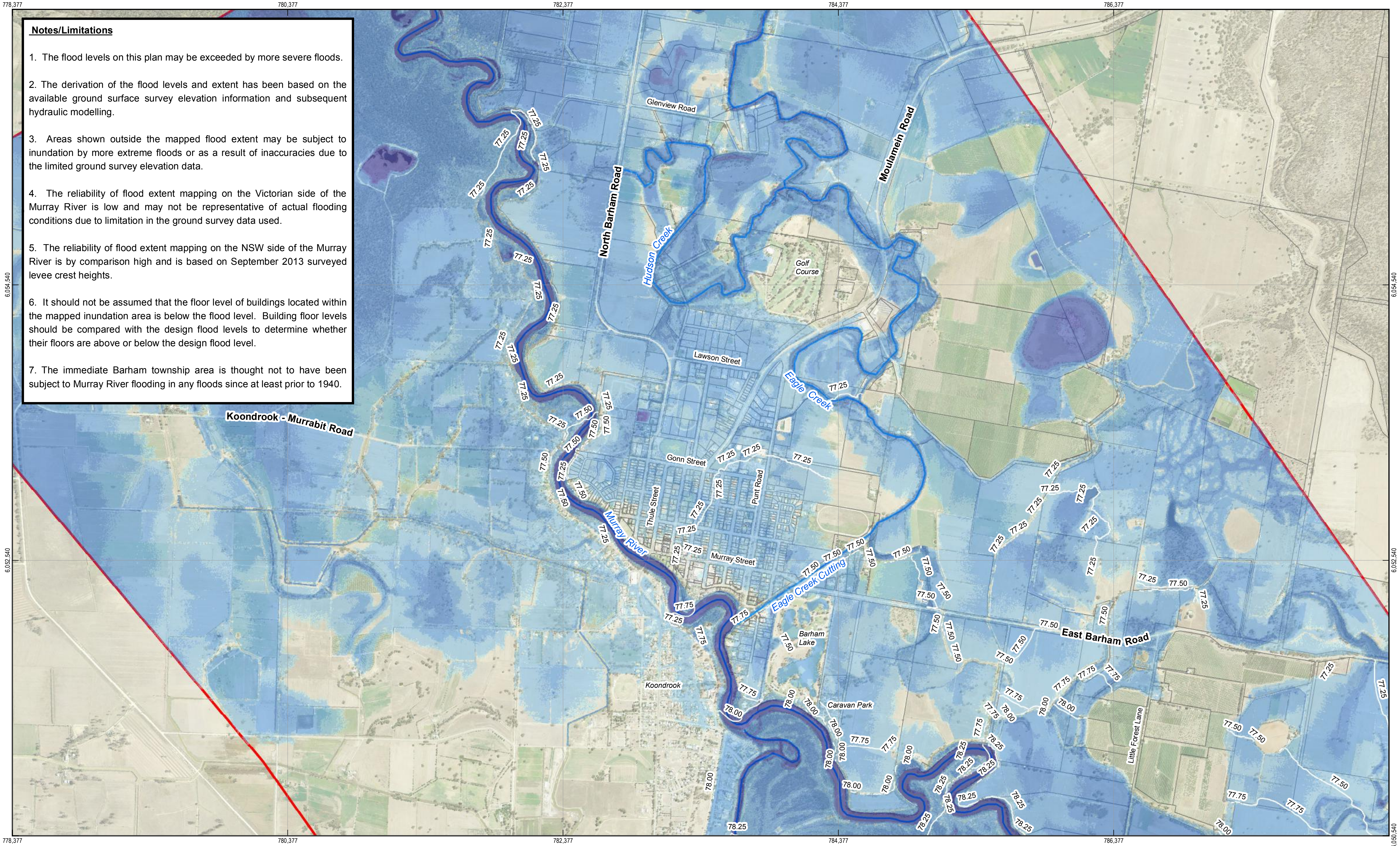
Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas


180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com




**Notes/Limitations**

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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

**Flood Extent and Depth (m)**

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00
- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

Wakool Shire Council
Barham Flood Study

| | |
|---|---|
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| Date | 07 Oct 2014 |

# Extreme Flood Event
# Flood Extent and Depth

Figure A6

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com



Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# Appendix B – Provisional Hazard Category Maps

**Notes/Limitations**

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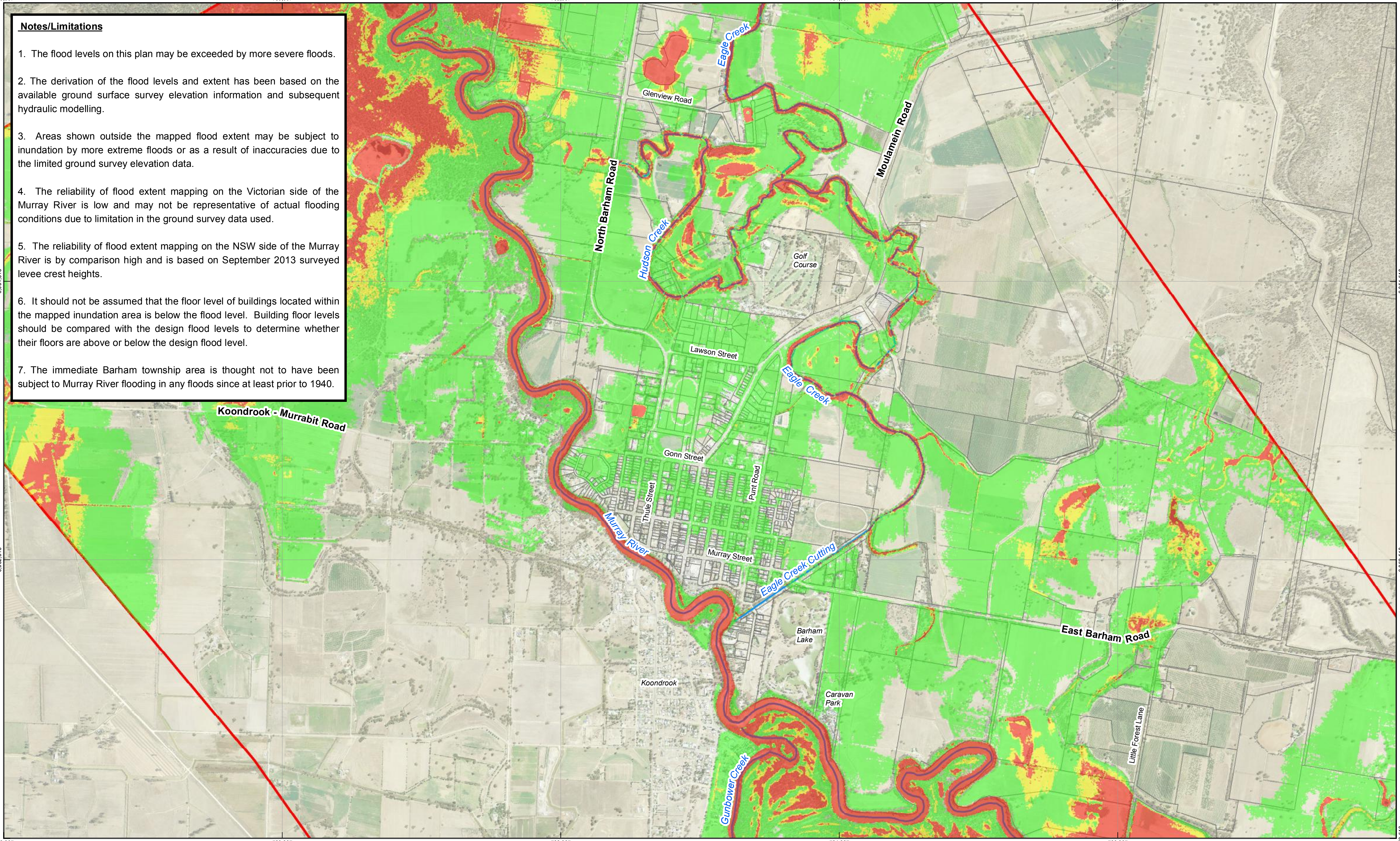


Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

1 - Low Hazard
2 - Intermediate Hazard
3 - High Hazard
Hydraulic Model Extents
Cadastre

GHD

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Wakool Shire Council
Barham Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

100-Year ARI Flood Event
Provisional Hydraulic Hazard Figure B1

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com



Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

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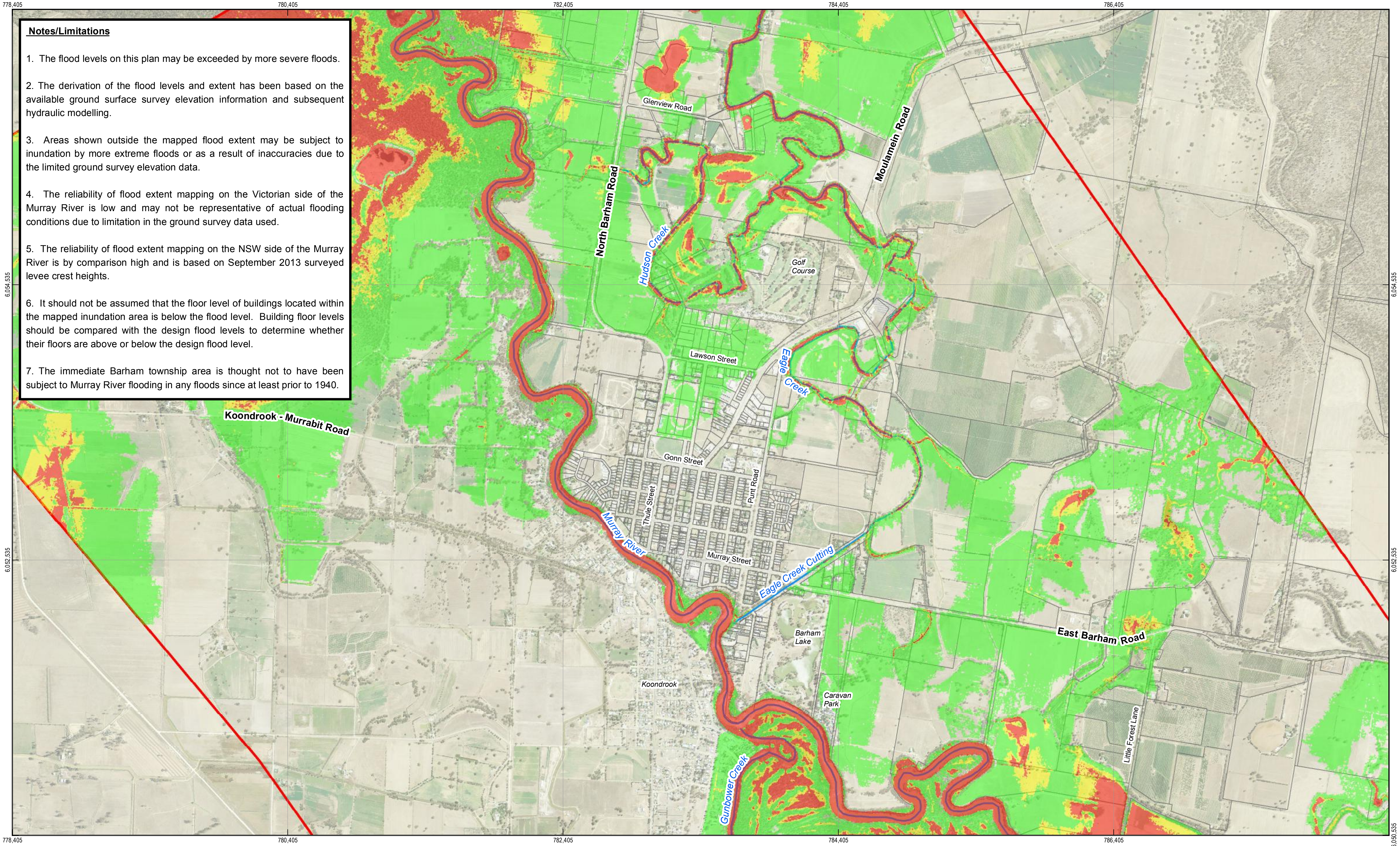


Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard
- Hydraulic Model Extents
- Cadastre

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Barham Flood Study

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| Date | 07 Oct 2014 |

20-Year ARI Flood Event
Provisional Hydraulic Hazard **Figure B2**

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com



Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# Appendix C – Hydraulic Category Maps

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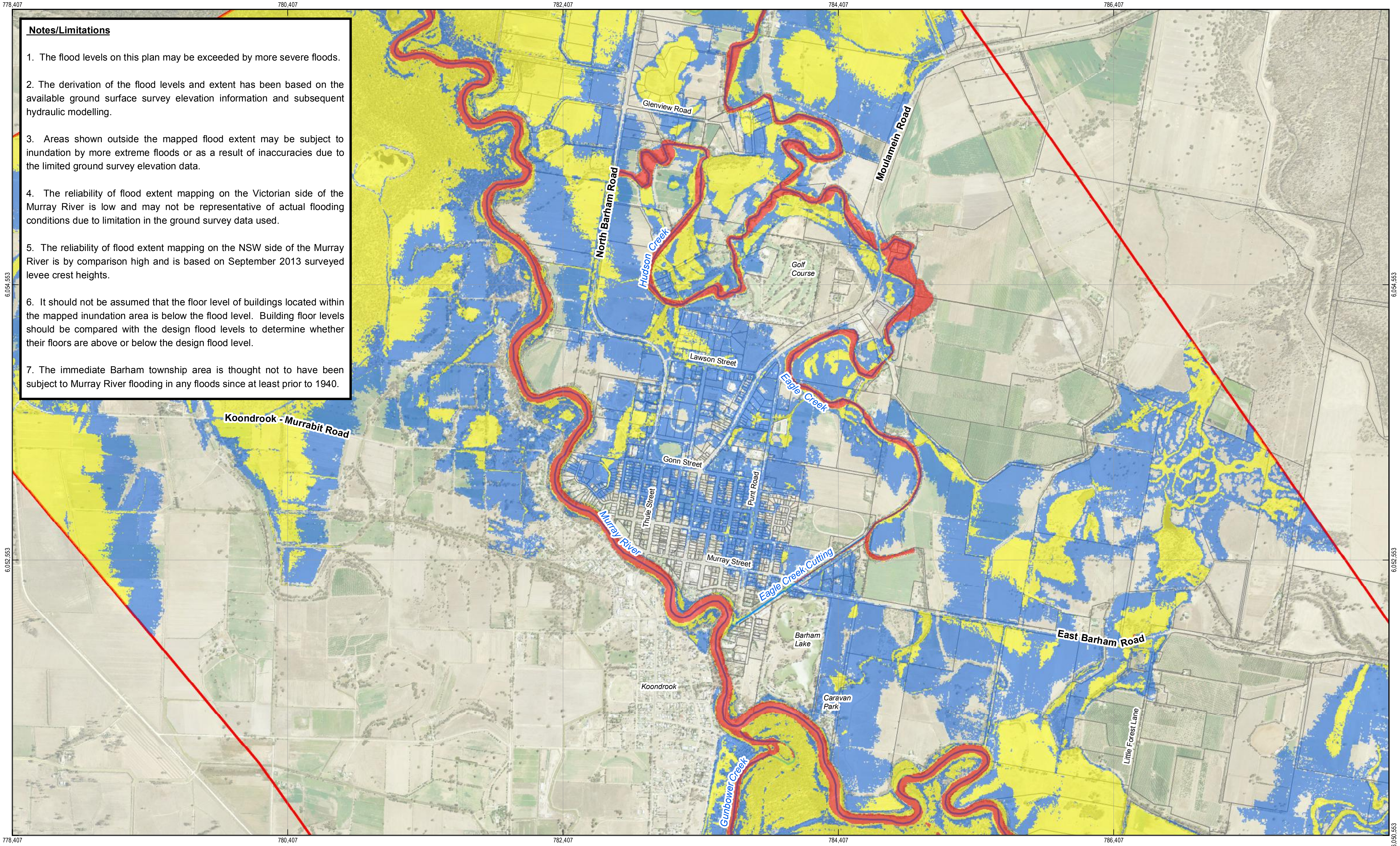


Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

- Flood Fringe
- Flood Storage
- Floodway
- Hydraulic Model Extents
- Cadastre

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Barham Flood Study

| | |
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| Date | 07 Oct 2014 |

100-Year ARI Flood Event
Hydraulic Category

Figure C1

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com



Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

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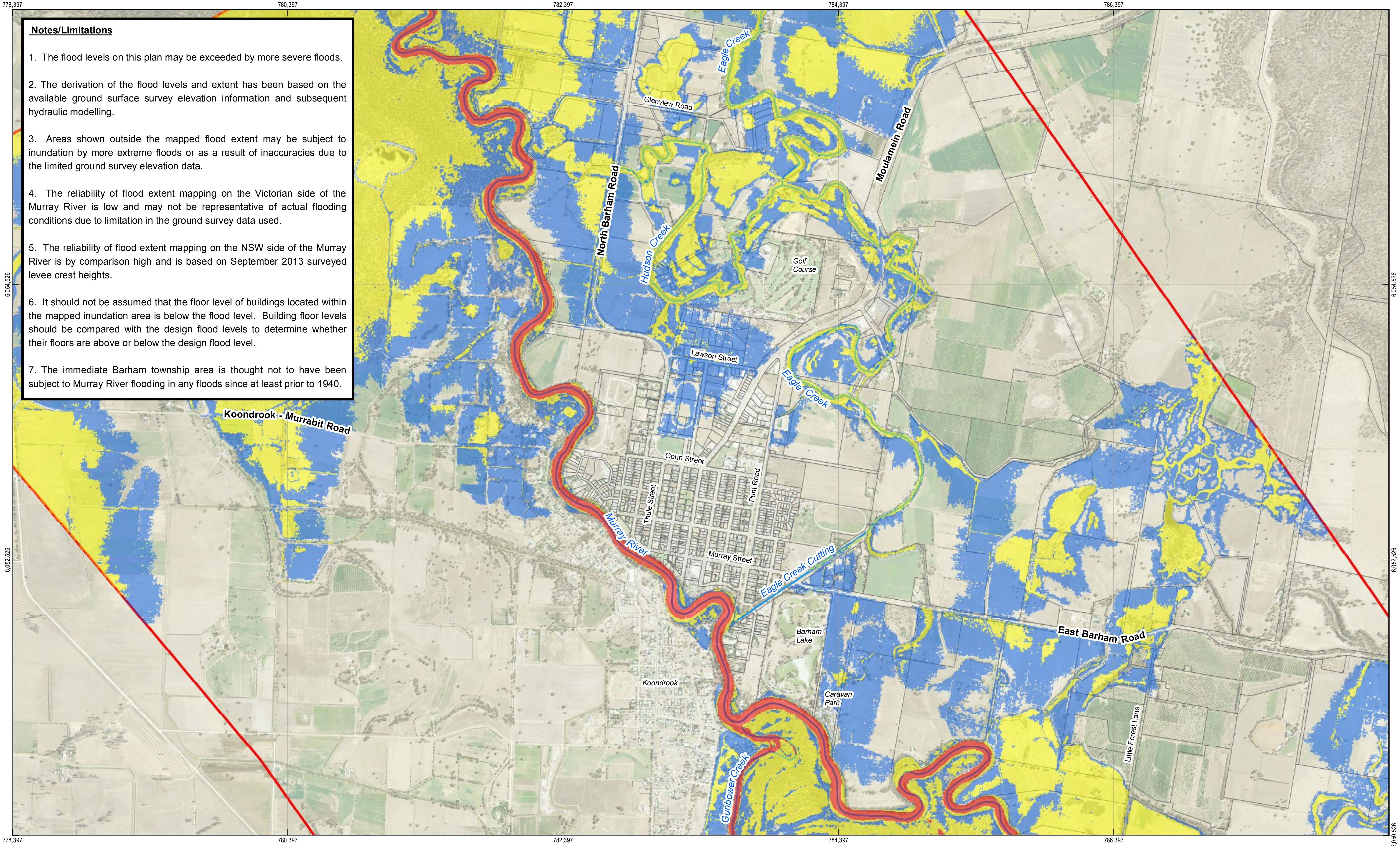


Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

**Legend**

- Flood Fringe
- Flood Storage
- Floodway
- Hydraulic Model Extents
- Cadastre

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Barham Flood Study

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| Date | 07 Oct 2014 |

20-Year ARI Flood Event
Hydraulic Category

Figure C2

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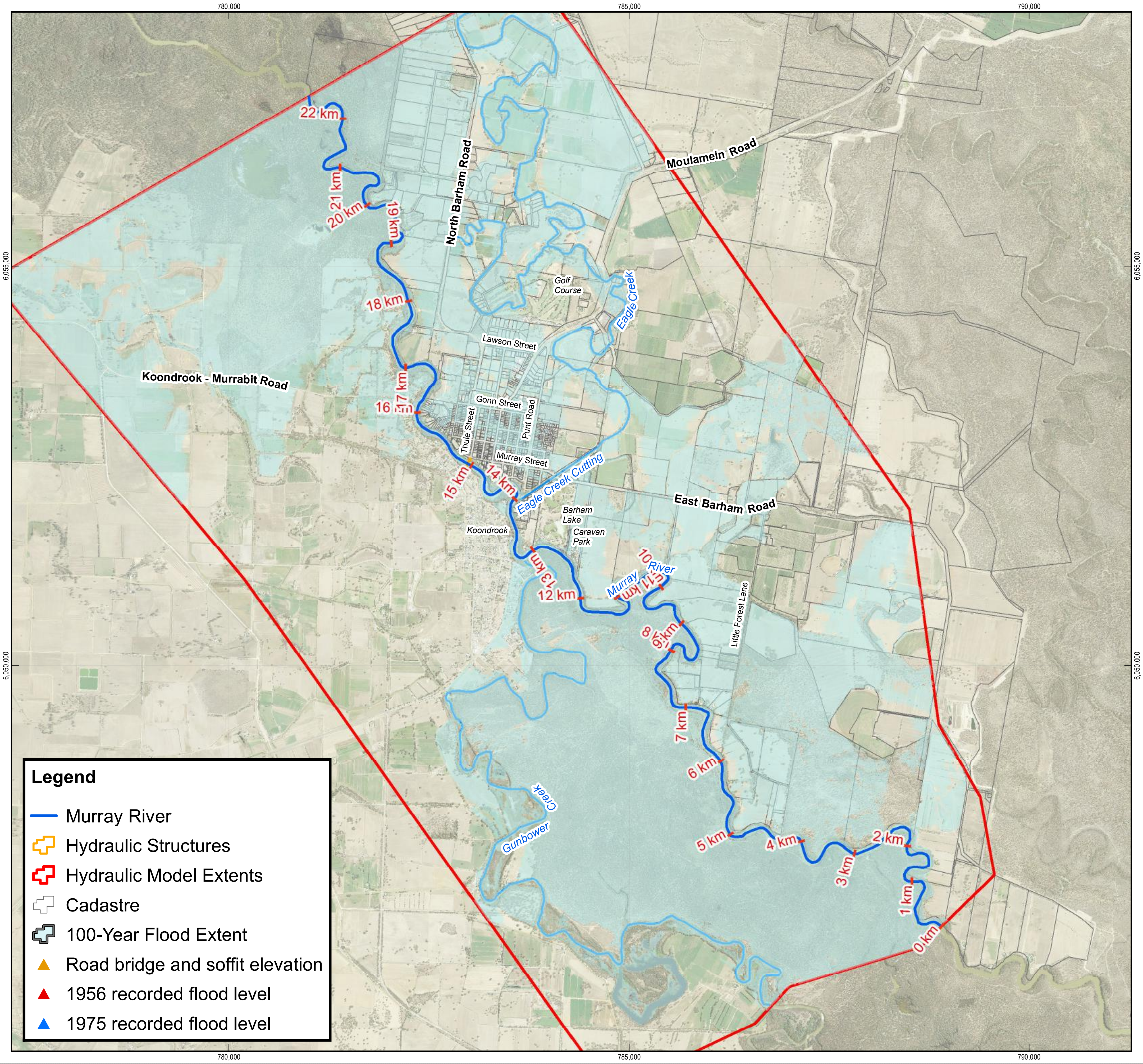
180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

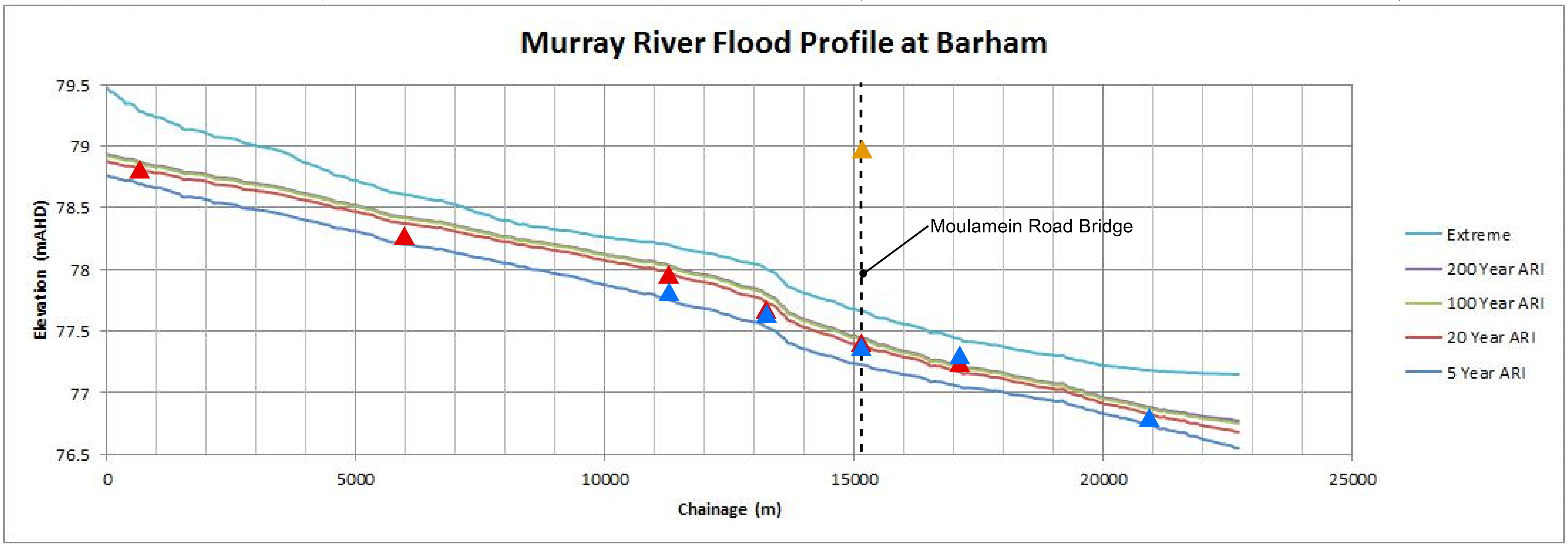


Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# Appendix D – Flood Profile Map

Figure D1 Flood Profile




Paper Size A3

0 250 500 1,000 1,500 2,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

GHD

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Wakool Shire Council
Barham Flood Study

Murray River
Flood Profile

| | |
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Figure D1

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E mwlmail@ghd.com W www.ghd.com


Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# Appendix E – Peak Annual Recorded Gauged Flows

## Table E1 Barham – Peak Recorded Flood Heights

| Year | Peak Flood Level (m) | Year | Peak Flood Level (m) | Year | Peak Flood Level (m) |
|---|---|---|---|---|---|
| 1914 | 3.28 | 1948 | 5.44 | 1980 | 4.60 |
| 1915 | 5.74 | 1949 | 5.74 | **1981** | **6.10 (rank 7)** |
| **1916** | **6.16 (rank 2)** | 1950 | 5.66 | 1982 | 2.72 |
| **1917** | **6.22 (rank 1)** | 1951 | 5.92 | 1983 | 6.02 |
| 1918 | 6.03 | 1952 | 5.94 | 1984 | 5.69 |
| 1919 | 4.80 | 1953 | 5.89 | 1985 | 5.45 |
| **1920** | **6.10 (rank 6)** | 1954 | 5.69 | 1986 | 5.74 |
| 1921 | 5.94 | 1955 | 6.02 | 1987 | 5.62 |
| 1922 | 5.33 | **1956** | **6.13 (rank 3)** | 1988 | 5.44 |
| 1923 | 5.79 | 1957 | 5.03 | 1989 | 5.93 |
| 1924 | 5.72 | 1958 | 5.85 | 1990 | 5.91 |
| 1925 | 5.46 | 1959 | 4.18 | 1991 | 5.76 |
| 1926 | 5.71 | 1960 | 5.88 | 1992 | 5.96 |
| 1927 | 5.10 | 1961 | 4.76 | **1993** | **6.10 (rank 8)** |
| 1928 | 5.66 | 1962 | 4.94 | 1994 | 3.44 |
| 1929 | 5.06 | 1963 | 5.18 | 1995 | 5.88 |
| 1930 | 5.51 | 1964 | 5.97 | 1996 | 5.94 |
| **1931** | **6.05 (rank 10)** | 1965 | 5.61 | 1997 | 3.66 |
| 1932 | 5.89 | 1966 | 5.56 | 1998 | 4.00 |
| 1933 | 5.72 | 1967 | 5.36 | 1999 | 4.84 |
| 1934 | 5.79 | 1968 | 5.73 | 2000 | 5.76 |
| 1935 | 5.79 | 1969 | 5.58 | 2001 | 2.74 |
| 1936 | 5.82 | 1970 | 5.94 | 2002 | 2.95 |
| 1937 | 4.04 | 1971 | 5.85 | 2003 | 5.08 |
| 1938 | 2.68 | 1972 | 4.63 | 2004 | 3.85 |
| **1939** | **6.13 (rank 4)** | 1973 | 6.05 | 2005 | 4.69 |
| 1940 | 2.99 | **1974** | **6.07 (rank 9)** | 2006 | 2.76 |
| 1941 | 4.70 | **1975** | **6.12 (rank 5)** | 2007 | 2.86 |
| 1942 | 5.79 | 1976 | 4.67 | 2008 | 2.68 |
| 1943 | 5.33 | 1977 | 4.44 | 2009 | 2.82 |
| 1944 | 3.02 | 1977 | 5.58 | 2010 | 5.99 |
| 1945 | 4.39 | 1978 | 4.44 | 2011 | 5.98 |
| 1946 | 5.69 | 1978 | 5.58 | 2012 | 5.87 |
| 1947 | 5.74 | 1979 | 5.95 | | |

Notes:

1. Levels are at the Barham streamflow gauge 409005 located on the downstream side of the Barham-Koondrook bridge. The peak flood levels were sourced from the NSW Government Waterinfo web site.
2. Gauge zero datum is 71.28 m AHD. Note that prior to 1998, the gauge zero datum was specified to be 71.435 m AHD. During 1998 or thereabouts, this was corrected to the current value of 71.28 m AHD following an AHD ‘datum shift’ at Barham. The absolute elevation of the gauge zero is understood to have not changed since 1905.

GHD

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Document Status

| Rev No. | Author | Reviewer | | Approved for Issue | | |
|---|---|---|---|---|---|---|
| | | Name | Signature | Name | Signature | Date |
| A | T Clark | R Berg | | R Berg | | 9/5/2014 |
| B | T Clark | R Berg | | R Berg | | 17/6/2014 |
| 0 | T Clark | R Berg | | R Berg | | 7/10/2014 |

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